ontario educational television

grade 13 pssc physics
macrocosms & microcosms

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MINISTER'S MESSAGE

Technological aids are playing an increasing role in education. Among them is educational television. Its place in the school is without question, and its acceptance world-wide.

Educational television is a means not only of communicating new knowledge, but also of introducing new methods and techniques, and the importance of its role is witnessed in the fact that the developing countries of the world are introducing this medium into their educational plans as early as possible.

The present series of programs in Grade 13 Physics and Grade 7 Mathematics will launch the Department's educational television broadcasts, and I trust that teachers will use them to the best advantage with their pupils. It must be remembered that a successful ETV program is not the result of a single effort, but a partnership between the studio and the class receiving the broadcast. If one fails the other, the program cannot be effective and successful.

Plato once said, 'The instrument is useful only to the man who knows how to use it and has had enough practice in the use of it'. Educational television is such an instrument.

William G. Davis

MINISTER OF EDUCATION
November 24, 1965.

Grade 13 Physics

James C. Fraser was born in Regina and received his early education in Toronto.

He was an honour Mathematics, Physics and Chemistry student at the University of Toronto and graduated with a first class honours Bachelor of Arts degree.

After serving as a naval officer he returned to Toronto in 1945, attended the Ontario College of Education in Toronto and then joined the staff at Lawrence Park C.I. where he taught Mathematics and Physics.

He moved to Jarvis C.I. to be Head of Physics Department in 1960. After attending a Physical Sciences Study Committee summer institute he volunteered to teach the full P.S.S.C. Physics course to Grade Eleven in 1964 and since then has given much of his time to helping teachers throughout Ontario become better acquainted with the techniques of teaching P.S.S.C. Physics, especially as it applies to Grade Thirteen.

Mr. Fraser leads a very active life in both his professional and private capacities. In his school he has been involved in the Physical Education program, is a football coach, and takes part in the Camera Club, the Cadet Corps, and is President of his Federation local. He was a co-author of the basic text book in electricity, radio, and radar that is used in the Royal Canadian Navy.

He is married, has five boys and one girl and is known as a supporter of, and an active participant in, his local church affairs.

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Grade 13 Physics
SATURDAY MORNING BROADCASTS

Please <u>NOTE</u> this revised telecast schedule cancels and replaces the schedule previously issued.

ETV PROGRAM SCHEDULE

STATION	JANUARY				FEBRUARY				MARCH				APRIL					MAY				SATURDAY
	8	15	22	29	5	12	19	26	5	12	19	26	2	9	16	23	30	7	14	21	28	TELECASTS
CFTO Toronto	1	2	3	4	5	6	7	8	9	10	11	12	13	SCHOOL VACATION — NO TELECAST	SCHOOL VACATION — NO TELECAST	14	15	16	17			12 noon
CKLW Windsor	1	2	3	4	5	6	7	8	9	10	11	12	13			14	15	16	17			11.30 a.m.
CFPL London		1	2	3	4	5	6	7	8	9	10	11	12			13	14	15	16	17		12 noon
CHCH Hamilton			1	2	3	4	5	6	7	8	9	10	11			12	13	14	15	16	17	11.30 a.m.
CKWS Kingston	1	2	3	4	5	6	7	8	9	10	11	12	13			14	15	16	17			12 noon
CJOH Ottawa		1	2	3	4	5	6	7	8	9	10	11	12			13	14	15	16	17		10.00 a.m.
CJSS Cornwall		1	2	3	4	5	6	7	8	9	10	11	12			13	14	15	16	17		10.00 a.m.
CHOV Pembroke			1	2	3	4	5	6	7	8	9	10	11			12	13	14	15	16	17	10.30 a.m.
CKVR Barrie	1	2	3	4	5	6	7	8	9	10	11	12	13			14	15	16	17			11.30 a.m.
CKNX Wingham		1	2	3	4	5	6	7	8	9	10	11	12			13	14	15	16	17		1.30 p.m.
CKCO Kitchener			1	2	3	4	5	6	7	8	9	10	11	SCHOOL VACATION — NO TELECAST	SCHOOL VACATION — NO TELECAST	12	13	14	15	16	17	10.00 a.m.
CKSO Sudbury	1	2	3	4	5	6	7	8	9	10	11	12	13			14	15	16	17			11.30 a.m
CJIC S. Ste. Marie		1	2	3	4	5	6	7	8	9	10	11	12			13	14	15	16	17		11.30 a.m.
CFCH North Bay	1	2	3	4	5	6	7	8	9	10	11	12	13			14	15	16	17			1.15 p.m.
CFCL Timmins		1	2	3	4	5	6	7	8	9	10	11	12			13	14	15	16	17		11.30 a.m.
CKPR Pt. Arthur			1	2	3	4	5	6	7	8	9	10	11			12	13	14	15	16	17	11.30 a.m.
CHEX Peterborough			1	2	3	4	5	6	7	8	9	10	11			12	13	14	15	16	17	1.30 p.m.

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PROGRAM NO. 6

TEACHER'S GUIDE

Elastic Collisions and Stored Energy

INTRODUCTION

This program teaches the properties of an elastic collision by examining, in detail, the interaction of two colliding dry ice pucks. By measuring the kinetic energy of each puck at every stage of the collision one is led to the concept of stored or potential energy. This program relates directly to sections 24-5 through 24-8 of the PSSC textbook. The viewing of this telecast will be helpful in the study of sections 25-1, 25-3 to 25-6, and of 29-7. An acquaintance with the properties of elastic and inelastic collisions is also needed for the study of Chapter 34 in connection with the Franck-Hertz experiment.

MAIN POINTS OF THE BROADCAST

1 The program begins with a very complicated inelastic collision in which the earth is one of the bodies involved. Kinetic energy disappears.

2 When a player bats a ball, the earth is again one of the bodies involved in the collision. The situation is still too complicated to be analysed.

3 Frictionless, dry ice pucks on a horizontal surface are used in the program as colliding bodies. These form a system which is isolated from the earth. Collisions between these pucks when a lump of putty is placed between them, or when metal hits metal, again show a loss of kinetic energy in the system as a whole. It is stated that the lost kinetic energy went into heating the putty or the metal.

4 In the next situation, two tall cylindrical pucks are used, each of which contains a magnet. This is demonstrated by showing that they can either attract or repel each other.

5 A head-on collision between these pucks shows that the kinetic energy before collision is equal to the kinetic energy after collision. This kind of collision is an *elastic* collision in contrast to the inelastic type where kinetic energy is permanently lost to the colliding bodies. However in *both types* of collision, *momentum is conserved.*

6 To study exactly how kinetic energy is transferred from one object to another in an elastic collision, the kinetic energy of each is measured at various times throughout the collision.

7 The kinetic energy is calculated from a strobe picture showing the positions of the pucks at regular time intervals. The displacement ($\triangle d$) in the equal time intervals is measured. The kinetic energy is calculated in the following way:

$$E_K = \frac{1}{2} mv^2$$

$$\text{but } v = \frac{\triangle d}{\triangle t}$$

$$\therefore v^2 = \frac{(\triangle d)^2}{\triangle t^2}$$

$$\text{Substituting, } E_K = \frac{1}{2} m \frac{(\triangle d)^2}{\triangle t^2}$$

but m and $\triangle t$ were constant throughout the collision,

$$\text{therefore } E_K = (\text{a constant}) \times (\triangle d)^2$$

$$\therefore E_K \propto (\triangle d)^2$$

Therefore, any change in $(\triangle d)^2$ causes a corresponding change in E_K, and therefore, $(\triangle d)^2$ is used as a relative measurement

of E_K in all the calculations. Since the pucks have equal masses, one only needs measurements of $(\triangle d)^2$ to compare the kinetic energies of the two pucks.

8 The following table is then derived:

Time Interval	$\triangle d_1$	$\triangle d_2$	$E_{K_1}=(\triangle d_1)^2$	$E_{K_2}=(\triangle d_2)^2$	TE_K	S
1	28.0	—	784	—	784	208.5
2	27.5	—	756	—	756	180.5
3	27.5	—	756	—	756	153.0
4	27.0	—	729	—	729	126.5
5	27.0	—	729	—	729	100.0
6	25.5	?	650	?	650	77.0
7	23.0	5.0	529	25	554	57.5
8	19.0	10.0	361	100	461	47.0
9	15.5	16.0	240	256	496	51.0
10	15.5	19.5	240	380	620	67.0
11	15.5	21.5	240	462	702	90.0
12	16.0	22.0	256	484	740	116.0
13	16.0	22.5	256	506	762	143.5
14	16.0	22.5	256	506	762	171.5
15	16.0	22.5	256	506	762	200.0
16	16.0	22.5	256	506	762	228.5

9 A graph of TE_K versus time is shown (see graph #1) and the significant features are discussed. The concept of stored energy is then introduced.

10 The separation of the pucks at regular time intervals is measured and a graph of TE_K versus separation is plotted (see graph #2). From this it is observed that the stored energy (or lost K.E.) depends only on the separation.

11 A graph of stored energy versus separation is then plotted (see graph #3, solid line). Other collisions are tried, and in every case, the stored energy follows the same relationship to separation between the pucks.

12 To prove that the stored energy is completely capable of being recovered, independent of the *time* that it is stored, two pucks are tied together with a string. The string is then burned, releasing the pucks. They both gain kinetic energy. The total kinetic energy is calculated and plotted on the same axes as stored energy versus separation. (See graph 3, dotted line).
The pucks started with a separation of 56.5 mm and possess a certain amount of stored energy. They should have this amount of kinetic energy when released. The experiment confirms this to be true. This illustrates that an elastic collision was taking place between the pucks and that the stored energy depends *only* on the separation.

13 The sum of the kinetic and potential energies in a system is called the *total mechanical energy* of the system. A study of graph #3 shows that another way of describing the property of an elastic collision is to say that the total mechanical energy is a constant or is conserved.

14 The statement that stored energy depends only on the separation of the bodies is exactly equivalent to the statement in the text that the force of interaction between the colliding bodies depends only on the separation for an elastic collision.

15 The students are urged to analyze one of the collisions for themselves. The work sheets on these are available from either Stark Electronics, Ajax, Ontario or from Canadian Laboratory Supplies Ltd., 80 Jutland Road, Toronto, (work sheets stroboscopic photograph, elastic collision).

POINTS FOR DISCUSSION

1 The initial loss in energy of the incident puck during the first few time intervals before the target puck started to move is a result of the puck scraping the table top. This is easily

understood if one considers that the cylindrical puck is very top heavy. Furthermore, as it is floating on a very thin layer of gas, it would be almost impossible to push it so that it would not wobble at all. When it leans forward and backward, the puck scrapes on the table top, causing the irregular loss in kinetic energy before the collision starts.

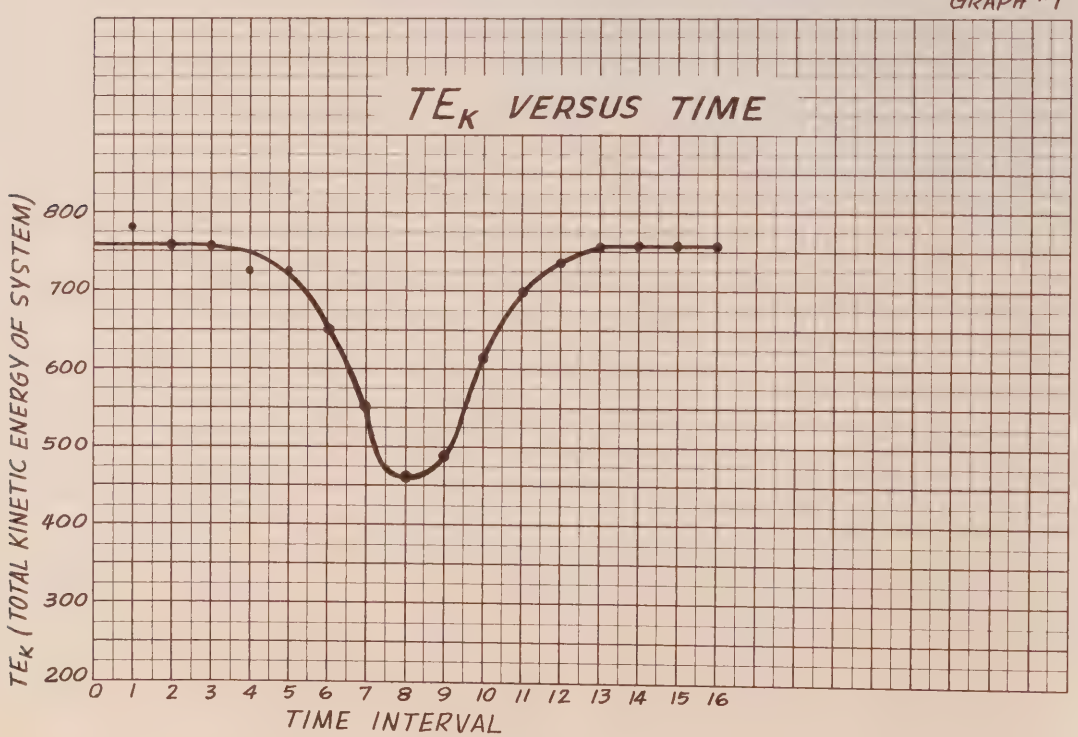
2 This program is particularly useful as an addition to the text because it illustrates the fact of "force of interaction depending only on separation" for an elastic collision in which the interacting force is a rather complicated function of separation. This is in contrast to the simple "step function" of force versus separation used in the initial development in the text.

3 In case any student asks what type of function exists between the force and separation, point out that it cannot be an inverse square relationship because of the two poles in each magnet. It is more likely an inverse cube law. It is of interest then to compare the function of the potential energy versus separation for the magnets (see graph 3) with that for a mass on the end of a spring (fig. 25-4 PSSC textbook) or for two equal charges (fig. 29-13, PSSC textbook).

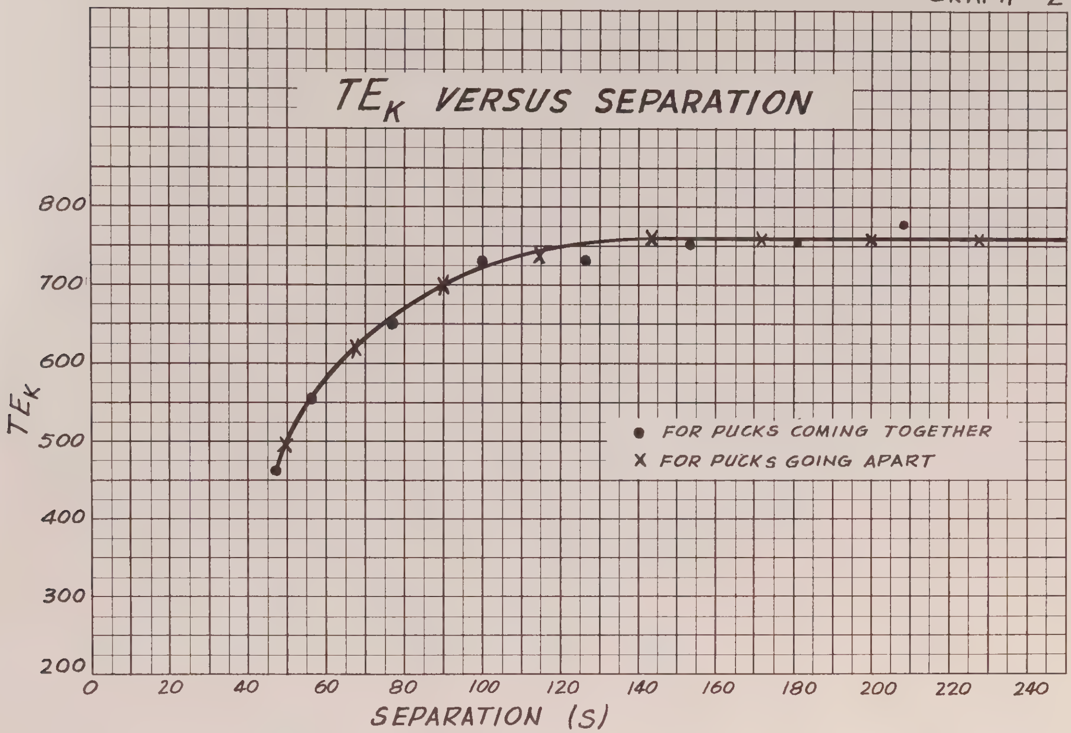
4 The usefulness of the potential energy concept in studying collisions should be emphasized. There is a gravitational potential energy associated with any two masses and an electrical potential energy associated with any two charged particles. If the collisions are elastic, we can use the laws of conservation of momentum and of kinetic energy to solve problems involving two bodies where the forces of interaction are *not known* (an example of this is the discovery of the neutron by Chadwick as outlined on pg. 399 of the textbook).

Even for inelastic collisions, the concept of potential energy is useful as long as one can predict the work done by the bodies (or by us on the bodies) as the separation of the bodies changes.

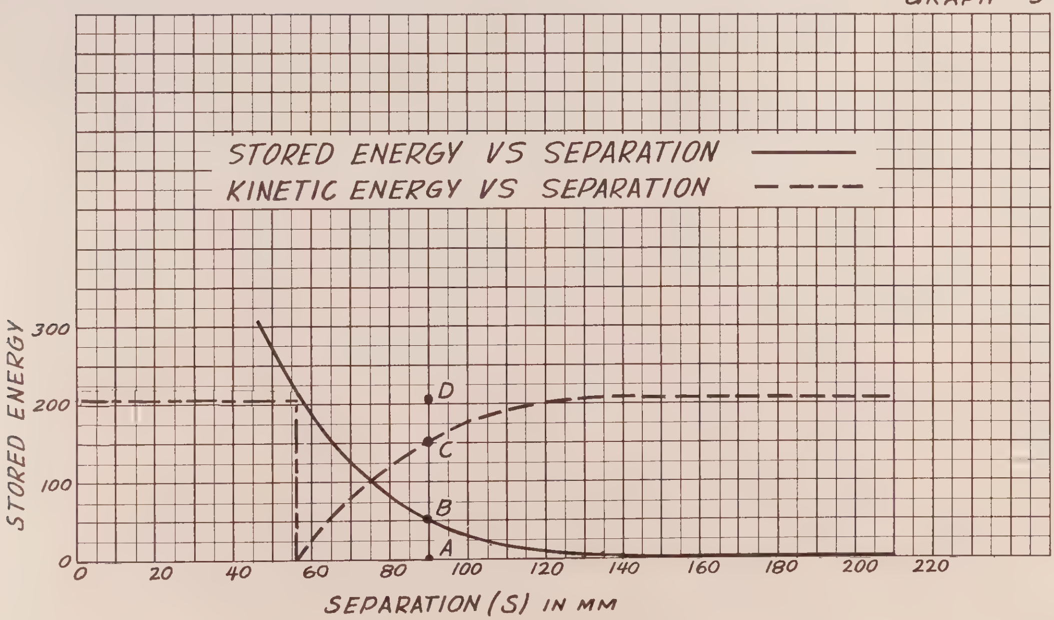
GRAPH #1



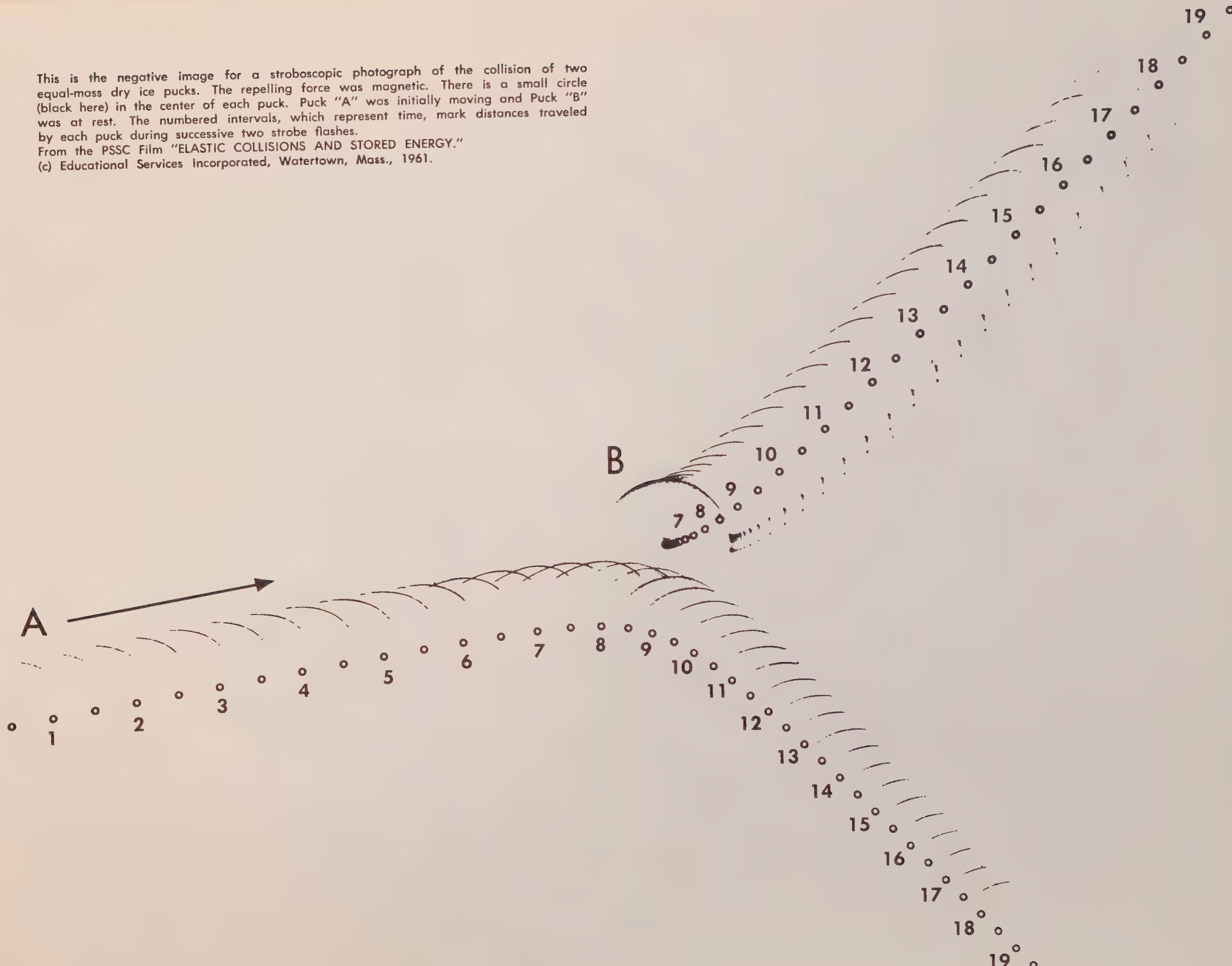
GRAPH #2



GRAPH #3



This is the negative image for a stroboscopic photograph of the collision of two equal-mass dry ice pucks. The repelling force was magnetic. There is a small circle (black here) in the center of each puck. Puck "A" was initially moving and Puck "B" was at rest. The numbered intervals, which represent time, mark distances traveled by each puck during successive two strobe flashes.
From the PSSC Film "ELASTIC COLLISIONS AND STORED ENERGY."



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PROGRAM NO. 7

TEACHER'S GUIDE

Mechanical and Thermal Energy

INTRODUCTION

This program demonstrates the transfer of kinetic energy of orderly bulk motion to the kinetic energy of random molecular motion (thermal energy). This explains what happens to the "lost" kinetic energy in an inelastic collision and illustrates what was meant by "heat" in Section 24-10 of the textbook.

The program also relates directly to Sections 26-1, 2, 3 and 5 of the PSSC textbook.

MAJOR POINTS OF THE BROADCAST

1. While observing the transfer of potential energy to kinetic energy in the case of a bouncing ball, it is seen that a loss of orderly mechanical energy is taking place. The question of where this energy went is then raised. It is suggested that the molecules of the air and also of the surface gained this energy.

2. To understand the loss of energy to the air, a model showing the behaviour of gas molecules is demonstrated. The purpose of the demonstration with this "marble machine" is to emphasize that in our study of a gas, we cannot study the behaviour of individual molecules, but must be satisfied with values of average behaviour such as measurements of pressure and temperature.

3. Temperature is explained to be the average kinetic energy of linear motion of molecules. The train of reasoning by which this is established, is as follows:
   The pressure of a gas is a result of the collisions of the molecules with the walls of the container.
   Pressure $\propto$ the momentum mv, and the speed v of the molecules
   Therefore, pressure $\propto mv^2$
   Therefore, pressure $\propto$ average kinetic energy of the centre of mass motion of molecules
   An experiment is then performed to show that the pressure of a gas in a container is $\propto$ to its temperature.
   Two different gases are used to indicate that all gases behave alike, at least in the range of temperatures from that of dry ice and alcohol to boiling water. By plotting a graph of pressure versus temperature, it is shown how the absolute temperature scale is derived. Since from this experiment $P \propto T$ and from the previous reasoning $P \propto mv^2$, it is concluded that $T \propto mv^2$ and hence we say that temperature is a measure of average kinetic energy of linear motion of the molecules.

4. Returning to the original question of how the bouncing ball lost energy to the gas, Professor Zacharias, in the film, illustrates the collisions between a ball and gas molecules by means of a model. In it we see the orderly kinetic energy of a dry ice disc (representing the ball) being lost and given to the random kinetic energy of small steel balls (representing gas molecules).

5. Professor Zacharias then returns to the marble machine to demonstrate the mechanism of thermal conduction.

6. The Principle of Conservation of Energy is *stated.*

7. Various methods by which energy may be transported are discussed, and some are illustrated.

ADDITIONAL DISCUSSION

1 The program is *not* intended to teach the law of conservation of energy. It cannot do so because no measurements are made at any stage of the program. It simply illustrates, with the aid of models, how mechanical energy is converted into thermal energy.

2 When Professor Zacharias makes the statement, "but with enough molecules, this chaotic motion takes on a certain order", what is understood is that with a large enough number of molecules, the average behaviour of the random motion becomes predictable. That is to say, the random fluctuations caused by having only a few molecules smooth out to be unobservable with sufficient molecules and we then measure only the gross properties of the gas. It is *not* meant that the motion of the molecules becomes orderly.

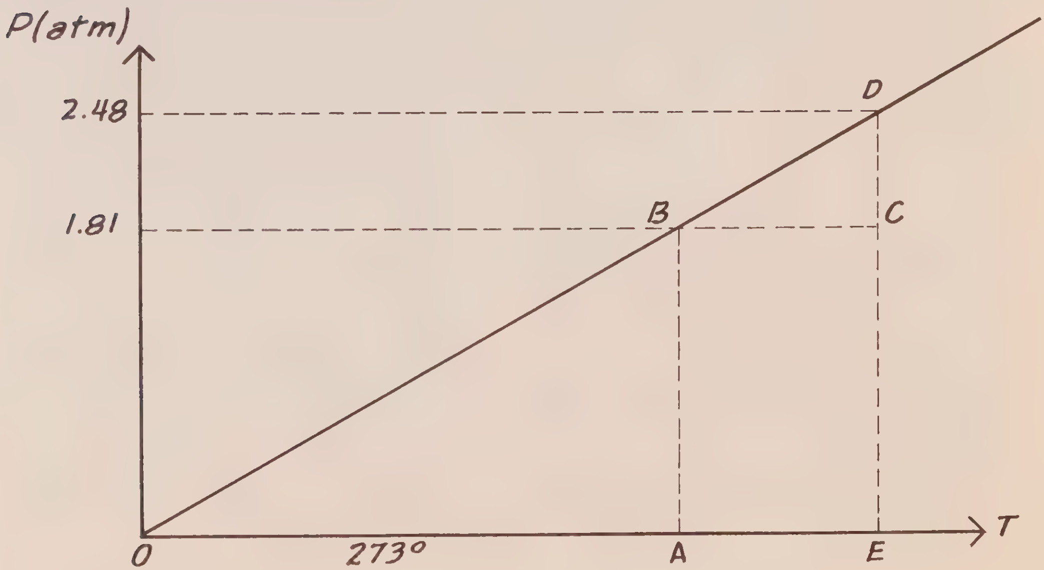
3 A "Brownian Movement Halt" indicates that the disc loses its orderly forward motion and comes to a condition where it jiggles around in a random manner under the influence of molecular bombardment. A student might ask why the object comes to a halt at all. This can be easily seen once he realizes that as the body is moving forward, the average bombardment on the front will exceed that from the rear, thus opposing the motion of the body.

4 It is interesting to note the method used by Professor Zacharias for setting the Kelvin Temperature Scale. The data from the program is shown on the following graph.
1.81 (atm.) was the pressure at the temperature of melting ice. 2.48 (atm.) was the pressure at the temperature of boiling water. Professor Zacharias started by *choosing* the temperature of melting ice to be 273°. He then plotted the point B, joined OB, and produced the straight line. Point D was then located on this line opposite 2.48 atm. and DCE constructed. Then, by comparing the similar triangles OAB and BCD, he found that BC (or AE) represented 100 units of Temperature.
This is the reverse of the usual method in which we choose 100 units of temperature to be between the melting point and the boiling point of water (i.e. we construct the centigrade scale), plot points B and D and then extrapolate backwards to zero pressure and find that the line meets the Temperature axis at 273 units below the temperature of melting ice.

5 Other pieces of experimental evidence in support of a kinetic theory of matter besides Brownian motion are:

(i) the natural noise generated within an electrical system

(ii) the velocity of sound in a medium is about the same as the average speed of the molecules in the medium.



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PROGRAM NO. 8

TEACHER'S GUIDE

Coulomb's Law

INTRODUCTION

This program introduces a quantitative study of the force Law existing between electric charges. It makes use of the PSSC film, Coulomb's Law, with Professor Eric Rogers of Princeton University. It relates directly to Section 28-1 through 28-3 of the textbook and laboratory experiments IV-3.

MAJOR POINTS OF INTEREST IN THE PROGRAM

1 Demonstrations showing the importance of electrical forces in nature and giving a rough idea of their magnitude.

2 Demonstrations recalling qualitative facts about the forces between electric charges.

3 Professor Rogers states that Coulomb's Law says "Force varies inversely as the square of the distance between the charges" and then emphasizes the meaning of an inverse square law by an intriguing illustration.

4 A diagram of Coulomb's original apparatus is shown.

5 Professor Rogers explains the operation of the spring balance type of apparatus which he is going to use in his experiments. He shows that each division on the scale represents a force of 1/10,000 of a newton, and therefore he will be able to estimate the force to within roughly 1/100,000 of a newton.

6 The experiment investigating the relationship between force and distance between two charged spheres is performed. The experimental data is as follows:

Dist.(d)	Force ($\times 10^{-4}$ newtons)	$\frac{1}{d^2}$	$F \times d^2$	
1 span	23.7	1	23.7	roughly a constant
2 spans	5.4	¼	22	
3 spans	2.5	1/9	22.5	

The experimental results confirm that the force varies inversely as the square of the distance. The generality of this law is then emphasized.

7 An experiment is performed to investigate the effect on the force of changing the quantity of charge on the spheres keeping the distance the same. It should be noted that the charge on a ball is reduced to one half of its original value by the technique of touching it to another neutral ball of the same size so that the original charge is shared equally between the two balls. The experiment shows that the force is proportional to the quantity of the charge on each of the spheres, within the limits of experimental error.

8 Professor Rogers pointed out that good scientists often formulate general laws on rather poor evidence but this is fine as long as the result is then rigorously tested. He then goes on to devise a very sensitive test of the inverse square law for electrical point charges. He reasons from an assumption that the inverse square law is correct and from the geometry of a sphere that there must be no net force on a test charge placed anywhere inside a charged hollow metallic sphere. This prediction is then tested experimentally.

9 Another test is performed to show the need for

a completely closed conducting surface around the test charge.

10 It is then stated that the result holds for any closed conducting surface even though there may be many holes in the surface. This is demonstrated by means of a huge wire cage.

ADDITIONAL POINTS FOR DISCUSSION

1 It will be recognized that the "ancient charging device" used by Professor Rogers is the electrophorus. It is suggested that you take this opportunity to review charging by induction as discussed in Section 27-5 of the PSSC textbook.

2 The students should realize that it is not possible by means of the electrophorus to recharge the spheres with the same quantity of charge each time. Consequently in the investigation of the inverse square law between force and distance when the *charge* was *constant* it was necessary to work quickly because there is always some leakage of charge from the metal spheres.

3 The technique of designing an apparatus which gives a zero reading as the correct result when testing a physical law or making a measurement is one which is frequently used when doing very precise experimentation, (e.g. the null point when using a bridge circuit to measure resistance, capacitance, etc.). As is pointed out in the PSSC Teacher's Guide, since the exponent 2 in $1/r^2$ is known to one part in 10^9, it is obvious that no direct measurement of force could produce such accuracy.

4 In a part of the film which it was not possible to use in the program, Professor Rogers asks the question "What would gravity be like inside a hollow earth?". Since gravity also obeys an inverse square law, the gravitational force would be zero at any point inside an earth which was a hollow spherical shell. However, for gravity the null result would only be obtained with a *spherical* body whereas for electrical forces the null result is obtained inside a conductor of *any* shape. This occurs because electrons are free to move in a conductor and will always arrange themselves on the surface of the hollow closed conductor until the force on a charge inside is zero.

5 The inverse square law is strictly true only for point charges or when the charge is distributed evenly over the surface of a sphere. Two charged metal spheres do not obey an inverse square law exactly due to the effect of induced charges on each other. However as long as the distance between them is several times their diameter the effects of uneven distribution of charge due to induction may be ignored and the inverse square relationship may be demonstrated quite well.

6 Page 28-4 in the PSSC Teacher's Guide gives more information on charge sharing and also some excellent quiz questions.

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PROGRAM NO. 11

TEACHER'S GUIDE

Elementary Charges and the Transfer of Kinetic Energy

INTRODUCTION

This program presents a large segment of the PSSC film bearing the above title. The film features Professor Francis L. Friedman of M.I.T. The purpose of the broadcast is to illustrate an experimental check on the assumptions made in Sections 29-1 and 29-2 of the text. The program particularly relates to Section 29-5 of the text.

MAJOR POINTS OF INTEREST

The following points outline the development of thought in the program:

1 At the beginning of Chapter 29 of the text, the assumption is made that for a charge being accelerated from rest in the electric field between two parallel plates, the force (F) on the charge times the distance (d) between the plates, equals the kinetic energy possessed by the charge after traversing the distance (d). The main purpose of this broadcast is to illustrate an experimental check of this assumption.

2 An introduction is again made to the arrangement of parallel plates which was used in the Millikan experiment. This provides us with a known electric force of 1.4×10^{-14} newtons per elementary charge.

3 The Millikan apparatus is modified in four ways:

(i) the plastic spheres are not used to carry the charges

(ii) the charges are provided by the emission of electrons from a hot filament

(iii) the plate from which the electrons leave is thin and the one they hit is a thick copper plate.

(iv) the space between the plates is highly evacuated.

4 The total kinetic energy possessed by all the electrons passing between the plates in a given time is *predicted*. The development of this prediction is as follows:

(i) the K.E. gained by one el.ch.
$= F \times d$
$= 1.4 \times 10^{-14} \times 3.1 \times 10^{-3}$ newton-m
$= 4.34 \times 10^{-17}$ joules

(ii) the number of el.ch. passing across in 1 sec. is measured by putting an ammeter in the circuit. A current of 2 ma or 2×10^{-3} Amperes is used, but 1 Ampere $= 6.25 \times 10^{18}$ el.ch./sec.
$\therefore$ number of el.ch. passing across per sec.
$= 6.25 \times 10^{18} \times 2 \times 10^{-3}$
$= 1.25 \times 10^{16}$

(iii) the total energy carried across per sec.
$$= 4.34 \times 10^{-17} \times 1.25 \times 10^{16} \left\{\frac{\text{joules}}{\text{el.ch.}}\right\} \left\{\frac{\text{el.ch.}}{\text{sec.}}\right\}$$
$$= 5.4 \times 10^{-1} \frac{\text{joules}}{\text{sec.}}$$
The charges, therefore, carry 5.4×10^{-1} joules per second to the thick copper plate.

(iv) To obtain a larger total amount of energy, the current is allowed to run for 20.5 secs.
$\therefore$ the total energy carried by the charges to the thick copper plate during one run is
$$5.4 \times 10^{-1} \times 20.5 \left\{\frac{\text{joules}}{\text{sec.}}\right\} \times \left\{\text{secs.}\right\}$$
or 11.0 joules.

Prof. Friedman summarizes the above reasoning by the one formula:

$$\left\{\frac{\text{Force}}{\text{el.ch.}}\right\}\left\{\text{dist}\right\}\left\{\frac{\text{el.ch.}}{\text{sec.}}\right\}\left\{\text{time}\right\} =$$

Total energy transferred by the charges to the thick copper plate.

Giving *units* this would appear as follows:

$$\left\{\frac{\text{newtons}}{\text{el.ch.}}\right\} \times \left\{\frac{\text{m}}{1}\right\} \times \left\{\frac{\text{el.ch.}}{\text{sec.}}\right\} \times \left\{\frac{\text{sec.}}{1}\right\} =$$

newton-m = joules

5 By a demonstration of heat energy being generated in a piece of lead when it is struck with a hammer, one is reminded that kinetic energy completely turns into heat during a perfectly inelastic collision. Therefore, the kinetic energy of the electrons is going to be measured by noting the temperature rise of the copper plate when it is struck by the electrons. A thermocouple is used for this and it is observed that a 24-division deflection of the thermocouple meter corresponds to the predicted energy of 11 joules.

6 In order to check on the fact that such a deflection does indeed correspond to a gain in energy of 11 joules, the temperature rise of an identical copper plate is measured when 11 joules of mechanical energy from a falling weight is transferred to it by means of friction.

The data is as follows:

Mass of falling weight = 1.5 kg
Distance it falls = 1.5 m.

Therefore loss in mechanical energy is mgh

$$= 1.5 \times 9.8 \times 1.5$$
$$= 22 \text{ joules}$$

Half of this is transferred to each of the two identical thick copper plates.

The thermocouple meter deflection was 23.5 divisions which checks that 11 joules went into one thick copper plate.

7 It is emphasized that just because the prediction worked with one set of values does not prove the general validity of the formula. (A check with a different set of values was actually done in the complete film). The formula, by numerous experimental checks, has been found to be true for all cases.

8 Professor Friedman points out that the prediction of the amount of energy transferred to the electron was done with no mention of the speed of the electron. This must mean that the force on the electron is independent of the speed when the charges on the plates are standing still. Professor Friedman warns us that the force is not independent of the speed when the charges exerting the force on the electron are moving.

9 He explains that this experiment also shows there is only one elementary charge in nature. He refers to the two kinds we dealt with in this experiment as the "Millikan elementary charge" and the "Faraday elementary charge".

ADDITIONAL DISCUSSION

1 Professor Friedman also stated that when the charges are accelerated over the same distance by the same force, they end up by moving about 1.5 times faster. When the force is doubled, the kinetic energy for elementary charge is doubled and hence, the speed is increased by a factor of $\sqrt{2}$ and $\sqrt{2}$ is approximately equal to 1.5

2 To be sure that all of the 22 joules given up by the falling mass went into heating up the thick copper plates, the following precautions were taken when designing the apparatus:

(i) the bearings supporting the axle were almost frictionless,

(ii) the axle was insulated from the copper disc so that no heat would flow into it, and

(iii) the final kinetic energy of the falling mass was negligible compared to the total loss of its potential energy. This was achieved by adjusting the force of the spring which pressed the copper plates together.

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PROGRAM NO. 12

TEACHER'S GUIDE

Electric Lines of Force and Electron Mass Determination

INTRODUCTION

This program is designed to provide a general survey of the types of force field which can be used to affect the motion of charged particles. It reviews certain aspects of the electric fields which have been read in the earlier chapters of the recommended text, and also the work on electromagnetism in the Grade 11 course. Both studies are a necessary preparation for the work on electromagnetic waves. The broadcast includes the PSSC films "Electric Lines of Force" featuring Dr. Alexander Joseph of Bronx Community College, New York, and "Electrons in a Uniform Magnetic Field" which introduces Professor Dorothy Montgomery of Hollins College, Virginia. The second of these films shows an alternative method of determining the mass of the electron to the one shown at the beginning of Chapter 29 of the class text.

POINTS TO WATCH IN THE PROGRAM

1 The meaning of an electric force field is established.

2 Dr. Joseph uses a 7500 volt transformer of the type used in neon signs to produce his electric fields. As a safety factor, he connects a 20 megohm resistor in the circuit between each terminal of the transformer and the electrode which dips into the mineral oil.

3 Lines of force always leave the surface of the conductor at right angles. This can be seen clearly in each of the four different field patterns which Dr. Joseph demonstrates.

4 Certain "Properties of Lines of Force" are listed and one example of the usefulness of these properties is given.

5 The operation of an electron gun from a cathode ray tube is explained as a practical example of the application of electric fields. In particular, the electrostatic focussing of an electron beam should be noted.

6 The type of force field so far discussed is the type in which a fixed distribution of charge acts on a moving charge. With this type, the force on the moving charge is independent of its speed as was established in last week's program.

7 A review of the magnetic field around a straight conductor carrying a steady current is presented. It should be noted that this steady magnetic field results from a steadily moving electric field. Any charge moving perpendicular to this magnetic field experiences a thrust which is perpendicular both to the magnetic field and to its direction of motion. The strength of this thrust or force is *not* independent of the speed of the moving charge.

8 It should be noted that in the Leybold tube, the electrons are acted on, in the first instance, by an electric field to give them kinetic energy, and then by a magnetic field which changes their direction but does not change their kinetic energy, since the force exerted by the magnetic field is always perpendicular to their direction of motion.

9 The mass of the electron is determined as follows:

(i) Since the P.D. in the electron gun was 100 volts and 1 volt $= 1.6 \times 10^{-19} \dfrac{\text{joules}}{\text{el.ch.}}$

and the Energy of a charge (q) accelerated through a P.D. of V volts is given by $E = qV$

$\therefore$ kinetic energy of an electron $= \frac{1}{2}mv^2 = qV$

$$\therefore \tfrac{1}{2}mv^2 = (1) \times 100 \times 1.6 \times 10^{-19} \ (\text{el.ch}) \left(\frac{\text{joules}}{\text{el.ch.}}\right)$$

$$\therefore \tfrac{1}{2}mv^2 = 1.6 \times 10^{-17} \text{ joules} \qquad (1)$$

(ii) The centripetal force on an electron in a magnetic field is given by $\frac{mv^2}{r}$ from dynamics and by Bqv from a knowledge of magnetic fields (see Sec. 30-8 in text).

$$\therefore \quad \frac{mv^2}{r} = Bqv$$

$$\text{or} \quad mv = Bqr$$

From a calibration curve for the Helmholtz coils, Dr. Montgomery realises the magnetic field strength for any given current in the coils.

She finds $B = .97 \times 10^{-22} \dfrac{\text{newtons}}{(\text{el.ch. /sec})(\text{meter})}$

$$\therefore \quad mv = .97 \times 10^{-22} \times 1 \times r$$

By means of a photographic "trick" she finds $r = .055$ m

$$\therefore \quad mv = .97 \times 10^{-22} \times 1 \times .055 \ \frac{\text{newtons}}{(\text{el.ch. /sec})(\text{meter})} \times (\text{el.ch.}) \times (\text{meter})$$

$$\therefore \quad mv = 5.34 \times 10^{-34} \ (\text{newtons-sec.}) \qquad (2)$$

Solving equations (1) and (2) for m and v, we get

$m = .89 \times 10^{-30}$ Kg

$v = 6 \times 10^{6}$ m/sec

10 The dependence of r on B and V is shown. If we solve equations (1) and (2) to get a value for r, we get

$$r = \sqrt{\frac{2m}{q} \times \frac{V}{B^2}}$$

and from this it can be seen that increased V increases r and increased B decreases r.

11 The magnetic focussing of an electron beam as used in a television tube or in an electron microscope is explained.

12 The force exerted by a moving magnetic field on a stationary charge is demonstrated. It is pointed out that this leads to the idea of electromagnetic waves.

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PROGRAM NO. 13

TEACHER'S GUIDE

Electromagnetic Waves

INTRODUCTION

The aim of this program is to establish experimental evidence for the common properties of electromagnetic radiation over a wide range of wavelengths and thus establish the unity of the electromagnetic spectrum. This program, in conjunction with the reading of Section 31-12 of the PSSC text, will deal with the content of Section 4, Part IV of the course outline. The PSSC film shown in the program is entitled "Electromagnetic Waves" and it features Dr. George Wolga of M.I.T.

POINTS TO WATCH IN THE PROGRAM

1 The program opens with examples of electromagnetic waves from the radio wave part of the spectrum. It shows radio waves being used in the "broadcast band", the "short wave band", and the "microwave region" (as used with radar).

2 The range of wavelengths in the electromagnetic spectrum is pointed out from a chart.

3 A list of the properties common to radiation from any region in the spectrum is given. These are:

(i) the energy travels from sender to receiver as a wave and therefore exhibits common wave properties

(ii) the waves arise from accelerated charges

(iii) all the waves travel with the speed of light, and

(iv) the waves can be polarized and therefore are transverse waves.

4 Light being emitted from the electrons in a synchrotron is shown as proof that electromagnetic waves in the visible region of the spectrum arise from accelerated charges.

5 A double slit interference pattern, using a carbon arc source, is shown as evidence of the wave nature of visible light.

6 The polarization of light is explained and demonstrated as evidence that the waves are transverse.

7 The fact that X-rays arise from accelerated charges is explained.

8 An interference experiment with X-rays is performed. The interference takes place between waves being reflected from the planes of atoms in a crystal of lithium fluoride. A model of this type of interference phenomenon is demonstrated in the program by using a ripple tank before the actual X-ray experiment is performed. This establishes the wave nature of X-rays.

9 An experiment analogous to the double slit interference experiment previously performed with light is now shown with microwaves having a frequency of 9×10^9 cycles per second which corresponds to a wavelength of 3.3 centimetres. The microwaves are produced by a klystron tube and are led by means of waveguides to two horns which radiate the waves into space. The waves from the two horns start out in phase.

10 The fact that the waves are polarized is then demonstrated.

11 A metal reflecting screen is set up behind the receiving antenna, and standing waves are produced. The distance between two nodes (i.e. $\frac{\lambda}{2}$) is measured and the wavelength is calculated. This turns out, as previously stated, to be 3.3 cm.

12 One is reminded that the speed of these microwaves can be easily measured by the "radar technique", that is, by sending out a pulse of waves and measuring the time for the echo to return from an object a known distance away.

13 The final experiment in the program is performed with radio waves having a frequency of approximately 150 million cycles/sec. or a wavelength of about 2 metres. The fact that these longer wavelength waves also arise from accelerated charges and that they are polarized, is stressed.

14 The reasons for the belief in the unity of the electromagnetic spectrum are summarized.

(Note: The half-hour schedule of the program did not allow time for all the PSSC film to be shown and since the interference effects were identical to those obtained with the microwaves, they were omitted).

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PROGRAM NO. 14

TEACHER'S GUIDE

The Rutherford Atom

INTRODUCTION

This program introduces Chapter 32 of the PSSC textbook. The broadcast includes the PSSC film, "The Rutherford Atom" featuring Professor Robert Hulsizer of the University of Illinois. By means of qualitative experiments and demonstrations with models, the ideas leading to Rutherford's nuclear model of an atom are strikingly presented. Following this, the film illustrates how Rutherford's prediction of a Coulomb Force Law of repulsion for alpha particles colliding with the nucleus was verified by Geiger and Marsden.

MAJOR POINTS TO LOOK FOR IN THE PROGRAM

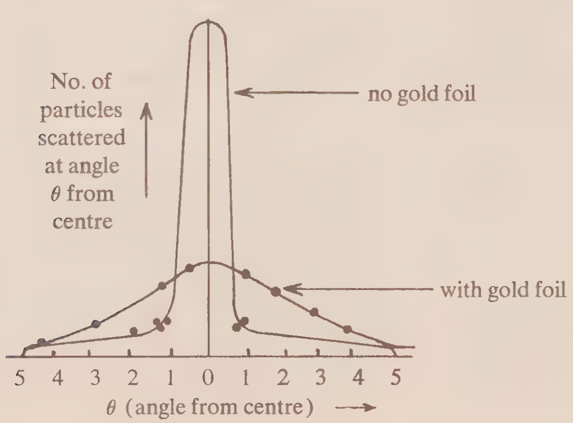
1 A reminder of the nature of alpha particles.

2 A comparison of the length of particle tracks in air without, and then with, a piece of gold foil in front of the radioactive source (polonium). The two distances, or the longest tracks, are about 4 and 3 scale divisions respectively.

3 A comparison is made of the distribution of alpha particles within a narrow beam before and after a piece of gold foil is placed in the path of the beam. The following graphs show the results of Geiger's original experiment.

4 A qualitative experiment showing the distribution of alpha particles in a wider beam (70°) is then illustrated. After finding and marking the edges of the beam, the detector is moved 25° out of the beam and the discovery of wide angle scattering is made.

5 A model is introduced which shows hot steel ball-bearings (representing alpha particles) being rolled down a ramp on to a sheet of waxed paper and then passed through a region which represents the gold foil. The hot balls leave tracks in the waxed paper so that it can be detected whether or not any collisions took place while the particles were passing through the "gold foil". It was observed that only six



Geiger did not find any α particles scattered through more than 5° on either side of centre

collisions took place out of approximately 200 tracks. On examining the model of the gold foil, it was found that there were hard steel pins at the places where the large deflections took place and that the rest of the space consisted of soft felt only. This leads to the idea of an atom consisting mainly of empty space which has the very light negatively-charged particles in it and with all the rest of the mass of the atom being very concentrated in a minute space at the centre. Furthermore, this massive core carries a large positive charge and this explains the wide deflections of the positively charged alpha particles.

6 The remainder of the film shows how Rutherford checked this view of the atom. He did this by finding out from a detailed study of the deflection angles what type of collision took place between the alpha particles and the nucleus. By "type of collision" is meant the kind of force law which exists between the colliding bodies.

Professor Hulsizer demonstrates three possible types of collisions:

(i) Magnetic collisions in which the force of repulsion obeys an inverse cube law.

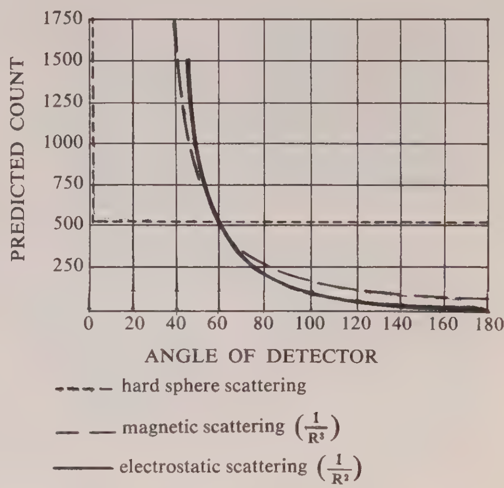
(ii) Contact or hard sphere collisions in which the force of repulsion arises very abruptly.

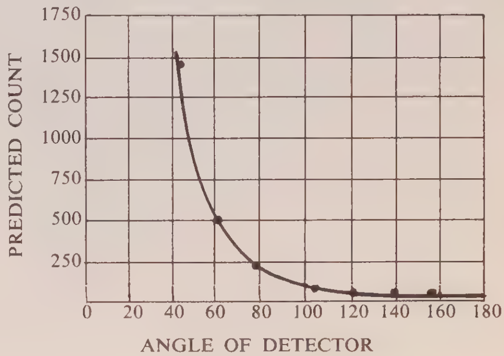
(iii) Electrostatic or Coulomb collisions in which the force of repulsion obeys an inverse square law.

For the same incident path each of these produces a different deflection angle after collision.

7 Rutherford suspected a Coulomb type interaction, and on this basis he calculated the angles through which the alpha particles would be deflected as a function of how directly they were aimed at the centre of the atom. All the different paths or trajectories are found to be hyperbolae. Professor Hulsizer shows some of these in a model of an atom.

8 Graphs of the number of alpha particles expected at each deflection angle for each kind of collision are shown. These are reproduced herewith, and we can see how Rutherford's prediction was verified.





The dots represent Geiger and Marsden's experimental results. They are compared with the curve characteristic of a $(\frac{1}{R^2})$ force as predicted by Rutherford.

9 Professor Hulsizer summarizes the views on the structure of the atom based on the above results. He states that Rutherford was also able to estimate the size of the nucleus and he shows, by means of a model, the relative dimensions of the whole atom and the nucleus in order to emphasize that most of the atom consists of empty space.

10 The program concludes with a brief discussion on the limitations of the Rutherford model of the atom and a suggestion that a new look at the nature of light will provide a clue to solve the difficulties.

ADDITIONAL DISCUSSION

It should be pointed out to the students that the scattering curves and experimental verification in this program are not the same as those discussed in the PSSC textbook. In the broadcast, the description is in terms of the number of particles scattered into a small angular range located at an average angle θ, whereas the PSSC textbook considers the total number of particles scattered through angles greater than some angle θ.

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PROGRAM NO. 15

TEACHER'S GUIDE

Photons and Interference of Photons

INTRODUCTION

In this program two PSSC films are shown, namely, "Photons" and "Interference of Photons". Both films feature Professor John G. King of the Massachusetts Institute of Technology. In the first film, an experiment is performed to demonstrate the particle nature of light and this relates to the study of Section 33-1 of the PSSC textbook. The second film demonstrates both the wave and particle nature of light in one experiment and in which an interference pattern is examined with a photomultiplier. The second film relates to the study of Section 33-3 of the PSSC textbook.

MAJOR POINTS OF THE PROGRAM

1 The viewer is reminded of some feature of the behaviour of light which could not be explained by the classical electromagnetic wave theory of light.

2 Professor King states that very weak light must be used in order to see the effect of individual light particles.

3 To study the light, a photoelectric cell is used. When light strikes the cathode in a photoelectric cell, electrons are given off and these are collected by a positive anode. The current through the cell is proportional to the amount of light striking the cathode. For the very weak light used in this experiment, the current is so small that an amplifier is needed to measure it. The amplifier which Professor King uses is a photomultiplier tube. This is a photoelectric cell with an amplifier built inside the same bulb. Professor King explains the operation of such a tube, and establishes that it amplifies the initial current from the cathode by a factor of about a million.

4 The output of the photomultiplier is fed into a cathode ray oscilloscope and its response, first to strong light, and then to very dim light, is demonstrated. He then explains that although pulses are seen in the second case, it does not necessarily prove that light comes in particles. He explains that even when no light falls on the photomultiplier, there are still some pulses. (These background pulses are a result of thermal agitation of the electrons). This thermal background or "noise" can be almost eliminated by cooling the tube. Professor King does this with a mixture of Dry Ice and alcohol.

5 Professor King then explains his outline for the main experiment. On the basis of a wave model, light energy comes in a continuous stream of waves, whereas in a particle model, light energy comes randomly in discrete bundles. On the basis of the wave theory, light energy falls on a surface in a continuous stream, whereas in the particle theory, light energy is given to a surface in discrete bundles in a random manner. Consequently in the first case, one would have to wait a definite length of time after the light was turned on before electrons in a metal surface would gain enough energy to cause photoelectric emission. In the second case, an electron would receive all the necessary energy in a moment and be emitted, and this could occur immediately after the light was turned on, or after any other random length of time.

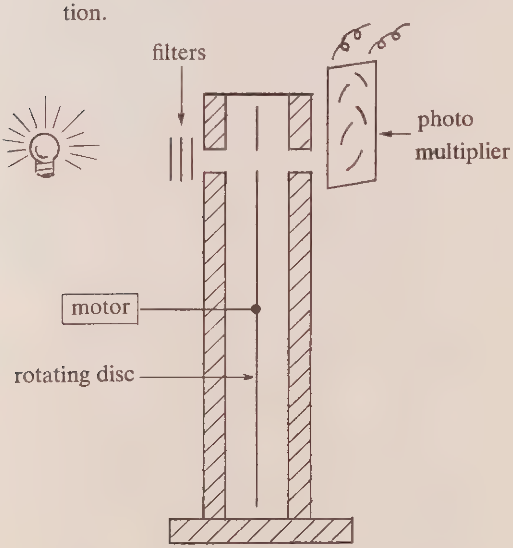
Professor King makes a comparison between this process and the delivery of milk. Suppose a person requires a quart of milk once a minute. The milk could be delivered in one of the following ways:

(a) by a pipe in which the milk flows at the rate of one quart every ten seconds, at

the beginning of every minute a gate opens and the milk flows, after a ten second wait, a quart bucket would be filled and then the gate closes. (Consider the milk as the light energy and the bucket as the electron which must receive a certain amount of energy before it can be emitted), or

(b) by a conveyor belt on which quart cartons of milk are placed at random intervals and when a gate at the end of the belt opens, the belt starts to move. The gate opens for 10 seconds once every minute, and on the average, the person receives one quart a minute. In this case, however, he might receive his quart immediately after the gate is opened or he might have to wait 5 or 10 seconds, or in one 10 second period he might not get any milk and the next time he would get 2 quarts. All this could happen because of the random distribution of the packages on the conveyor belt. This, of course, is comparable to electrons being emitted in a photoelectric cell at random time intervals after the light is turned on, rather than always having to wait a full 10 seconds. It is this idea which Professor King uses to find out whether light energy comes in packages (photons).

6 The "gate" corresponds to a skeleton, consisting of a rotating disc between two black walls. Where a hole in the disc lines up with the hole in the walls, the light gets through. This occurs for a brief instant once every revolution.



7 Filters are inserted between the source of light and the photomultiplier to reduce the light intensity by a factor 10^6. The output of the photomultiplier is then 3×10^{-10} amperes. Therefore, the input of the photomultiplier is 3×10^{-16}, since 1 ampere = 6.25×10^{18} el.ch./secs. This corresponds to $3 \times 10^{-16} \times 6.25 \times 10^{18}$, roughly 2000 electrons per second or, on the average, 1 electron every $\frac{1}{2000}$ second. This corresponds to the idea of 1 quart of milk in every 10 second interval (on the average).

8 The shutter disc is sprung at 60 revs/sec. and Professor King estimates from geometry that the shutter is open for $\frac{1}{5000}$ secs. every $\frac{1}{60}$ of a second. The lamp is directed through without filters and the pulse from the photomultiplier is fed into the cathode ray oscilloscope, and the $\frac{1}{5000}$ sec. time interval is marked on the screen.

9 The three filters are then inserted so that one is brought back to the case of 1 electron being emitted every $\frac{1}{2000}$ sec. If light comes in a continuous stream one should have to wait $\frac{1}{2000}$ sec. before an electron is emitted. Since the shutter is open for only $\frac{1}{5000}$ sec. after the light starts to show through, one should not get any pulses in this time interval. However, we do get pulses, some even within 6 microseconds after the shutter began to open. This means that light does not deliver its energy in a continuous stream but in particles. These particles are called photons. They are not like the simple particles referred to in Chapter 15 of the PSSC textbook, because they are intimately connected with waves as will be witnessed in the next film.

ADDITIONAL DISCUSSION

1 The experiment shown in the film cannot, on its own, conclusively demonstrate that light comes in packages. Additional experiments are necessary before one is justified in coming to a definite conclusion. These experiments involve a study of the mechanism of the absorption of light at the photocathode which leads to the emission of electrons and also a consideration of the efficiency of the cathode in the photomultiplier (i.e. what percentage of photons actually produce a photoelectron and what percentage are just "lost" in the surface). These and other experiments have

been performed and all conclusively support the idea of photons.

2 Students may rightly question whether the pulse seen at six microseconds after the shutter began to open is the result of a thermal electron or a photoelectron. However, since only one event is shown, it is statistically insignificant. This problem can only be solved by comparing the number of pulses seen at six microseconds which occur when the light is on, with the number of pulses seen without a light. This experiment, however, would have taken too much film time to perform.

3 The students will get a better idea why a smooth pulse is seen with strong light but a very erratic pulse is seen with weak light if they view the PSSC film, "Random Events".

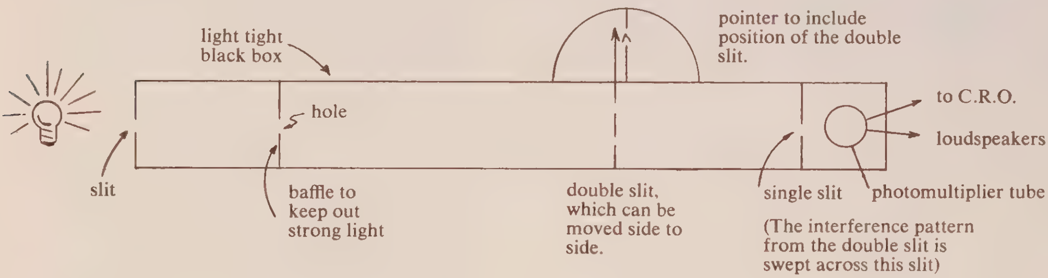
NOTE: After a short pause in the broadcast, the film, "Interference of Photons" is shown without any introduction because it carries on quite smoothly from the last remarks in the "Photons" film.

POINTS TO WATCH

PART 2

1 Professor King describes the apparatus with which he is going to show both the wave and particle nature of light in one experiment.

A diagram of the apparatus is illustrated below:



2 Without dimming the light source, Professor King moves the double slit back and forth and shows that he alternately gets a maximum and minimum. In other words, there is an interference pattern. He then leaves the double slit in such a position that the central maximum is on the photomultiplier slit.

3 The light source is dimmed so that the current coming out of the photomultiplier is 10^{-9} amperes.

4 The output of the photomultiplier is then put on a cathode ray oscilloscope and also fed through an amplifier into a loudspeaker. The double slit is then moved back and forth as before, and again maximum and minimum are observed. When a maximum is on the photomultiplier slit, pulses are seen on the C.R.O. screens. Professor King emphasizes that they are caused by photons.

5 He then explains that there is rarely more than one photon in the box at any one time. He explains this in the following manner:

(a) Output current of photomultiplier is 10^{-9} amps. but amplification factor of the photomultiplier is 10^6. Input current of photomultiplier is 10^{-15} amps. or $6.25 \times 10^{18} \times 10^{-15}$ electrons/sec. which is approximately 1,000 electrons/sec.

(b) The efficiency of the photocathode is approximately 10^{-3}. (This is a very conservative estimate). This means that, on the average, 1000 photons must strike the photocathode in order to emit one electron, and that $10^3 \times 10^4$ photons must enter the photomultiplier slit each second in order to produce a current of 10,000 electron/sec.

(c) If 10^7 photons are passing through the box per second, then 1 photon enters the box, on the average, every 10^{-7} seconds.

(d) Since photons *are* light, they travel at the speed of light, i.e. 3×10^8 m/secs. If photons enter the box one every 10^{-7} sec., this means that when one photon is entering the box, the one before it has already been travelling in the box for 10^{-7} seconds. In short, it has travelled $3 \times 10^8 \times 10^{-7} = 30$ m. or 100 ft. The box, however, is only 8 ft. long, therefore, in the main, there is only one photon in the box at a time, that is, one photon has passed through the double slit and hit the photomultiplier long before another photon enters the box.

The remarkable fact is that the interference pattern is characteristic of individual photons rather than the interaction between two or more photons.

6 Professor King points out that light, as distinct from any previously discussed models, behaves like particles and waves at the same time. One interprets this interference pattern (wave behaviour) of photons by stating that the probability of the arrival of photons at one place is given by the intensity of the pattern at that place. Where there is a maximum of intensity one is most likely to find photons. Where there is a minimum, one will find none.

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PROGRAM NO. 16

TEACHER'S GUIDE
Matter Waves

INTRODUCTION

This program presents the PSSC film, "Matter Waves" featuring Professor Alan Holden and Dr. Lester Germer of Bell Telephone Laboratories, New Jersey. It shows experimental evidence for the wave behaviour of particles of matter by showing that electrons produce interference patterns. (The broadcast refers directly to Section 33-8 of the PSSC textbook).

MAJOR POINTS OF INTEREST IN THE BROADCAST

1 Louis de Broglie in 1923, suggested that waves are also associated with ordinary particles of matter. In 1927 Davisson and Germer in New York City and G. P. Thomson in Cambridge, England, performed diffraction experiments showing that the De Broglie idea was right.

2 A shadow of an object may be cast by spraying particles at it; paint from a spray gun. This is the idea used in an electron microscope. Beams of electrons cast enlarged shadows of small objects on a photographic plate. An electron microscope photograph of smoke particles shows an interference pattern at the edges of the shadows of the particles. This is compared with the light and dark bands seen at the edges of the shadow of a razor blade illuminated by a small source of light. Hence a study of diffraction patterns is going to be used to check up on the idea that electrons behave like waves.

3 We are reminded of the behaviour of light where it strikes a diffraction grating. The spacing between the lines must be comparable to the wavelength of the waves we wish to diffract.

4 De Broglie's suggestion that the relationship $p = \frac{h}{\lambda}$ where p is the momentum of a photon should also hold for matter waves, is used to get an idea of the wavelength of the matter waves, and hence give us some idea of the line spacing needed to show a diffraction pattern with electrons.

Using this idea, the calculation is as follows:

Mass of electron $\approx 10^{-30}$ Kg

Speed of electron when accelerated through a P.D. of 100 volts $\approx 10^{7}$ m/sec.

$\therefore$ p of electron $\approx 10^{-23}$ newton-sec

$$\therefore p = \frac{h}{\lambda}$$

$$\lambda = \frac{h}{p} = \frac{6.62 \times 10^{-34}}{10^{-23}} \ \frac{\text{joules-sec}}{\text{newton-sec}}$$

$$\therefore \lambda \approx 10^{-10} \text{ m.}$$

This is about the size of an atom.

5 A grating with this spacing is obtained by using the orderly arrangement of atoms in a crystal. However, in this case the lines are in two perpendicular directions. The effect of using two single line gratings, one placed on top of the other, and the two sets of lines perpendicular to each other, is then illustrated. White light is first used followed by blue light to show the effect of different wavelengths.

6 An apparatus which will be used to perform a comparable experiment with electrons is then described. A beam of electrons is reflected

from the surface of a crystal onto a fluorescent screen which shows the diffraction pattern.

7 The scene changes to the Bell Telephone Laboratories in New Jersey where Dr. Germer performs an actual experiment with the apparatus described. He first uses 40 volts to accelerate the electrons and get a diffraction pattern typical of "crossed gratings". He then uses a higher voltage (47 volts). This means higher speed, therefore there is larger momentum, and shorter wavelength. This means that the pattern should shrink and it does so. Dr. Germer states that knowing the spacings of the atoms in the crystals and the angle of the beams in the diffracted electron pattern, he can calculate the wavelength of the electrons. This is exactly what he and Dr. Davisson performed in 1927 and he shows one of the first experiments taken from their original apparatus. He also states that they performed the first experiment in which electron diffraction was observed.

8 Dr. Holden then describes the experiment which G. P. Thomson performed in Cambridge, England, at about the same time. The main difference in the two experiments is that Thomson, using higher voltages, shot the beam of electrons right through the crystal. Transmission through a grating gives exactly the same effect as reflection from it. However, in going through a layer of crystals, the beam meets many gratings at random angles and a circular diffraction pattern is obtained instead of dots. He compares photographs taken by X-rays with one taken by electrons to show the close similarity.

9 Dr. Holden illustrates that *any* particles show this wave behaviour and not just electrons. He shows diffraction patterns obtained with beams of helium atoms and with beams of neutrons.

10 The program concludes with the idea that the wave-like behaviour of material particles is so well established that this fact is used as a tool in other researches, for example, to find out more about the arrangement of the atoms in other crystals.

ADDITIONAL DISCUSSION

1 Dr. Davisson and G. P. Thomson shared the Nobel Prize in Physics in 1937 for their work on these experiments.

2 G. P. Thomson was the son of Sir J. J. Thomson. It is interesting to note that prior to J. J. Thomson's experiments in 1898, streams of electrons were called cathode rays. Then J. J. Thomson received the Nobel Prize in 1907 for showing the corpuscular nature of electrons and his son received the same prize thirty years later for showing the *wave* nature of electrons.

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PROGRAM NO. 17

TEACHER'S GUIDE

The Franck-Hertz Experiment

INTRODUCTION

This program presents the PSSC film, "The Franck-Hertz Experiment" featuring Professor Byron L. Youtz of Reed College, Portland, Oregon. The aim of this program is to show that atoms can take on only certain definite amounts of energy which also means that they can exist only at discrete energy levels or states. In the broadcast, a slightly modified version of the original Franck-Hertz experiment is performed. It shows that when an accelerated electron makes an inelastic collision with a mercury atom, the smallest amount of energy it can give is 4.9 electron volts. The program relates directly to Sections 34-1 and 34-2 of the PSSC textbook.

MAJOR POINTS OF INTEREST IN THE BROADCAST

1 A photograph of the bright line spectrum of mercury in both the visible and ultraviolet regions recalls the fact that mercury atoms emit light only at certain distinct frequencies and wavelengths. Attention is directed to the line representing a wavelength of 2537 Angstroms. Since light energy comes from atoms in photons whose energy is proportional to the frequency, all photons coming out of the atom to make up this spectral line will have the *same energy*. The energy of each photon is given by the formula $E = \frac{12397}{\lambda}$ where λ is in Angstroms and E is in electron-volts.

2 If atoms lose energy in certain discrete bundles of energy, it seems reasonable to suggest that they can only absorb energy and be raised from one energy state to a higher one in steps having the same discrete energy values. The question then is "Can we cause a mercury atom to move from one energy state up to another energy state by a process which does not use photons?"

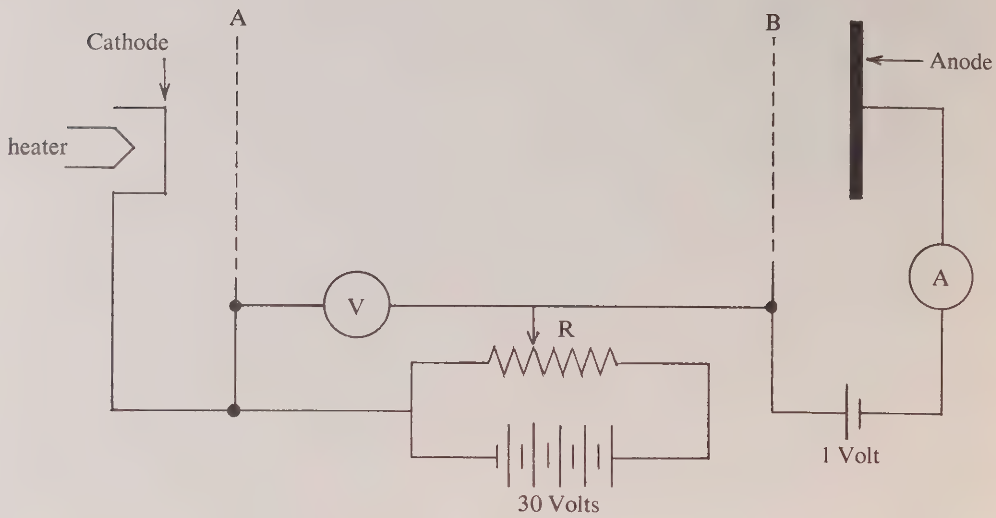
Can we, for example, make an electron collide with a mercury atom and give it just the right amount of energy to cause it to jump from one energy state to another?

3 This idea was tested in 1914 by James Franck and Gustav Hertz who were studying elastic and inelastic collisions between electrons and atoms, and the relationship of this to the emission of light.

4 A mechanical model consisting of a Dry Ice puck (representing a mercury atom) and a ping-pong ball (representing an electron) is used to illustrate the nature of elastic and inelastic collisions. The model, however, cannot establish the idea of absorption of energy only at discrete energy levels.

5 The construction of the special vacuum tube used in the actual experiment is illustrated.

The function of the parts is described by means of a schematic drawing.



The control grid A limits the number of electrons passing into the region between A and B.

B is the accelerating grid.

V measures the voltage between A and B which is accelerating the electrons across the gap.

This voltage can be varied by means of the potentiometer R.

The anode is held at a potential which is 1 volt negative with respect to B. Therefore, electrons which pass through B must at least, have an energy of 1 electron volt, in order that they reach the anode and be counted by the current meter A.

6 Professor Youtz shows that with very little mercury vapour between A and B, the current rises smoothly with the voltage to 30 V.

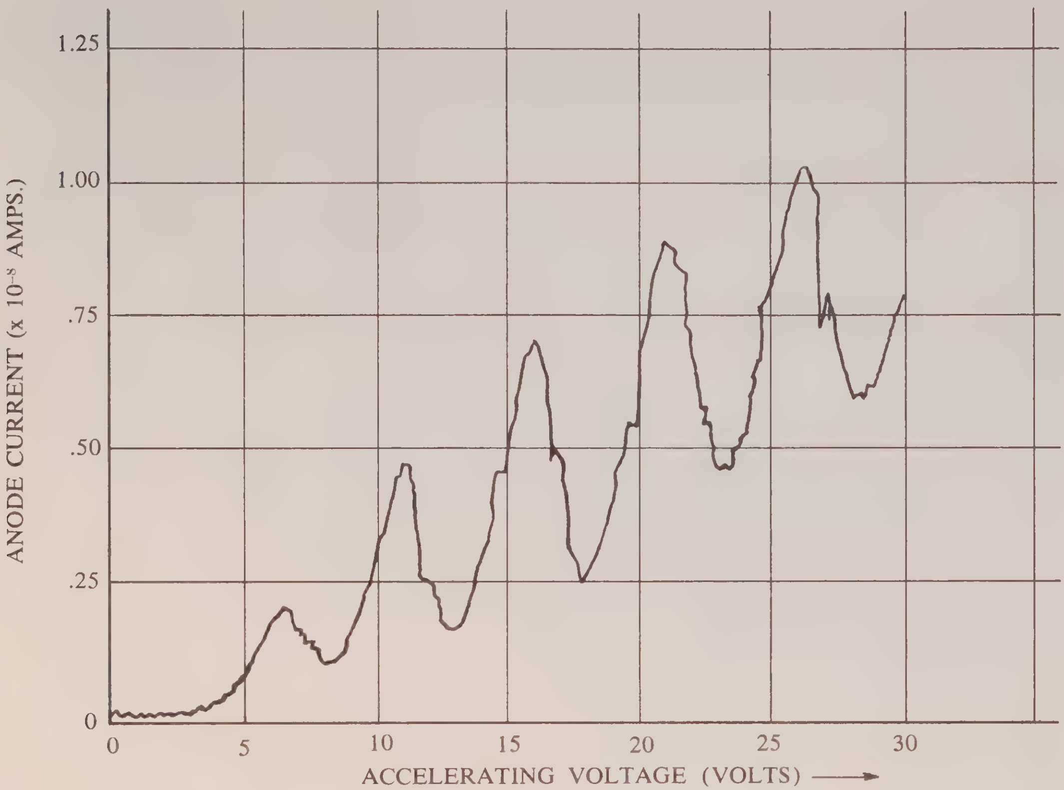
7 Mercury atoms are introduced into the path of the electrons by placing the tube (which has a large drop of mercury in it) into an oven at about 160°C.

8 Professor Youtz now predicts that if the voltage is raised as before, the current will rise until a voltage is reached at which the electrons gain just the right amount of energy to deliver the proper sized package to the mercury atoms near grid B. Then they will not have enough energy left to get up the potential kill between B and the anode, and so the current will drop.

9 He performs the experiment and the prediction seems to be correct. He then continues to increase the voltage and the current continues to rise and fall alternately.

10 Professor Youtz then repeats the experiment and makes a record of current versus accelerating voltage on an X-Y recorder.

The graph he obtained is similar to the one shown below:



On the average, the distance between peaks is about 4.9 volts. Two possible interpretations of this are given. It is shown that, in either case, it may be concluded that the smallest package of energy which a mercury atom can accept is 4.9 electron-volts.

11 This is checked against the relationship $E = \frac{12397}{\lambda}$ for the energy of photons emitted by an atom. For the spectral line $\lambda = 2537$ Angstroms $E = \frac{12397}{2537} = 4.9$ e.v.

This is an exact agreement with the prediction.

12 Professor Youtz briefly discusses possible new experiments which should be performed to check up on this new theory.

ADDITIONAL DISCUSSION

1 In the complete film, "The Franck-Hertz Experiment", there is an epilogue by Professor James Franck in which he describes an experiment where 4.9 e.v. electrons were used to bombard mercury atoms. The emission of these energy packages in the form of photons to produce the single spectral line of 2537 Angstroms was then observed. This provided an excellent check on the theory.

2 In 1925 Professors Franck and Hertz shared the Nobel Prize in Physics for their research in connection with the energy states of atoms.

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Grade 13 Physics

PREFACE

This Teachers' Guide has been prepared in relation to the series of educational television programs entitled, 'Macrocosms and Microcosms'.

The topics for the broadcasts have been selected from the present Grade 13 Physics course. Furthermore, each program will contain segments from the PSSC Physics films. The first four of the scheduled seventeen broadcasts are in the form of review lessons.

The broadcasts are scheduled on Saturday mornings to avoid interfering with the present school timetables. It is, however, hoped that teachers will view these telecasts and encourage their students to do so. In some areas, students may voluntarily wish to meet in small groups to watch and discuss the programs. It is also trusted that teachers, with the use of the material in this Guide, will introduce the topic of the broadcast in class in advance of the Saturday morning television presentation, and review the lesson early during the week following by using the suggested problems and follow-up activities mentioned in this brochure.

Each broadcast Guide contains a suitable introduction to the topic under study, an outline of the program content, and some suggested activities.

The broadcast scripts and the Guide outlines have been prepared by Mr. James C. Fraser, B.A., Head of the Science Department, Jarvis Collegiate Institute, Toronto. Mr. Fraser is also the 'on-camera' teacher-presenter of the series. Mr. Lincoln Steele, Assistant Superintendent, Curriculum Division, Department of Education has acted as subject supervisor during the preparation of the series.

The programs will include the following topics which will be broadcast in the order listed.

1 Straight Line Kinematics
2 Optics and Waves
3 Forces
4 Inertia and Inertial Mass
5 Frames of Reference
6 Elastic Collisions and Stored Energy
7 Mechanical and Thermal Energy
8 The Coulomb Law
9 The Millikan Experiment
10 Determination of Coulomb's Force Constant
11 Elementary Charges and Transfer of Kinetic Energy
12 Electron Mass Determination and Electric Lines of Force
13 Electromagnetic Waves
14 The Rutherford Atom
15 Photons and Interference of Photons
16 Matter Waves
17 The Franck-Hertz Experiment

The names of the local stations carrying the broadcasts and the times of the telecasts are listed on a separate page, so that the schedule might be placed on the class bulletin board for reference. The numbers in the respective columns refer to the program numbers listed above, for example, No. 1 is 'Straight Line Kinematics', No. 8 is 'The Coulomb Law', etc.

NOTE: This folder contains the outlines for the first few broadcasts only. The others will be issued as they are prepared. Please place them into this folder as you receive them.

Suggestions for Viewing Television in the Classroom

THE TELEVISION SET

1 Switch on the television set at least five minutes before the start of the program. Turn the volume control down and cover the picture by adjusting the doors of the set, or cover with drapery or other material. This will ensure a minimum of class interruption during the warm-up procedure.

2 Two minutes prior to telecast, make the necessary adjustments to the brightness and contrast controls to ensure picture clarity. Keep volume turned down.

3 Approximately twenty seconds prior to telecast time remove the screen cover and adjust the volume control. Try to avoid adjustments during the program telecast.

4 Window and other lighting reflections on the screen may occur if the television set is positioned at certain angles to light sources. This condition can be avoided by repositioning the television set or through the use of the cabinet doors. If no doors, cardboard shields may be easily fashioned and fixed to the set.

ENVIRONMENTAL FACTORS

5 It is not necessary to black out the classroom. If lighting can be slightly dimmed by closing window drapery or switching off some lights, acceptable light level should result.

6 Tests should be made prior to the broadcast, to ensure that the maximum benefits of viewing and listening are available to each pupil. The seating arrangements will obviously vary with room shapes, type of furniture and number of pupils, but no pupil should be placed in a position that is greater than a 45° angle from a line drawn straight from the centre of the picture tube. Using a 23 inch screen, the minimum distance between pupil and picture should be approximately five feet, and maximum distance from picture should be approximately twenty feet. The television receiver should be raised to a height so that the centre of the picture tube is approximately 66 inches above floor level.

7 These approximate measurements indicate that a square or wide classroom shape is much better than a long narrow room unless of course, desks can be turned towards a long wall or aligned towards a corner.

CAUTION: The measurements shown above are approximate. They may not apply to all classrooms and are offered as a guide only. Long extension cords, antenna leads, and insecure structures for the elevation of the television set should be avoided. Pupils should be discouraged from assisting in setting up the television set or making any adjustments to it.

Grade 13 Physics
PROGRAM 1

TEACHER'S GUIDE

Straight Line Kinematics

This is the first broadcast of the series, 'Macrocosms & Microcosms'.

MAIN POINTS OF BROADCAST

The major points included in this program are:

(a) Motion along a path and in one direction only is dealt with in this program — although the car seen in the film turns around.

(b) The question to be solved is how distance, speed, and acceleration vary with time for the motion of a car being driven along a road.

(c) The motion can be described by means of graphs; d – t, v – t, a – t. These graphs, as stated in the film by Professor Hafner, may be drawn by means of "black boxes", or "instruments of some unfamiliar kind". The graphs are called X – Y recorders because of the usual reference to the X & Y axis of a graph.

(d) All black boxes must be calibrated.

(e) Distance, speed, and acceleration as functions of time, are *not* independent physical quantities.

(f) Graphically, speed may be calculated from a d – t graph, and acceleration from a v – t graph, by taking slopes.

(g) Graphically, changes in speed may be calculated from an a – t graph, and changes in distance from a v – t graph, by finding areas beneath the curves.

(h) The importance of kinematics as a fundamental branch of physics.

IMPORTANT ITEMS TO BE OBSERVED

(a) The slope of the d – t graph at 25 seconds to find the speed.

(b) The straight region of the d—t graph from 20 seconds to 35 seconds means constant speed over this time interval.

(c) A curved line means changing speed. To obtain the speed at any instant, draw the tangent to the curve at that point. Question: to find the speed at 62.5 seconds.

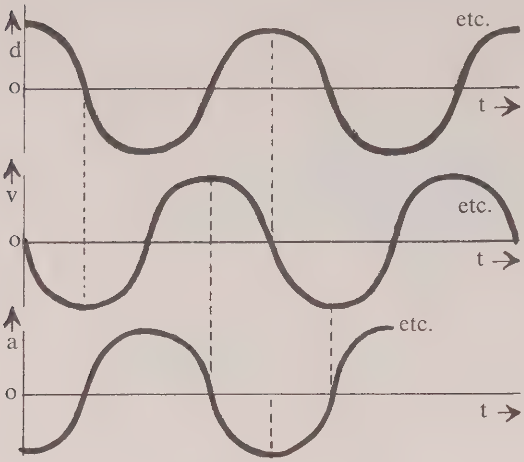
(d) The students should be directed to look for places where the acceleration is zero, and where it is constant. The students should also check the acceleration at 80 seconds and see how closely they agree with the value obtained in the program.

(e) Note that although the speed curve is decreasing slightly between 20 and 30 seconds, yet the acceleration is shown as slightly positive in this region. Therefore the recording instrument must be in error.

(f) The students should calculate the area under the a – t graph between 7 and 25 seconds and observe how this checks with the change in speed over this time interval. Since this is a *positive* area, it must represent an increase in speed. The significance of a negative area should also be noted.

(g) The area beneath the v – t graph between 7 and 47 seconds should be found and checked with the increase in distance over the same time interval. Similarly, the area beneath the graph from 57 seconds to 72 seconds should be found and checked with the delta d shown in the broadcast program.

(h) Question the students as to why the acceleration is a maximum when the speed in the case of the pendulum is zero. The students should plot their own v – t and a – t graphs from a displacement-time such as indicated on p.2. This is slightly different from the graph shown in the broadcast lesson.



(i) It would be possible to indicate to the students at this stage of their studies, that the reason why the acceleration is a maximum at the bottom of the swing for the plastic pendulum is due to the fact that this is where the force is a maximum. At the top of the swing in this type of pendulum it would be necessary to give a kinematical reason, namely, that over the short time interval at the top of the swing, the pendulum is changing direction and therefore the 'v' is going from positive to negative. Therefore the change in velocity is a maximum.

(j) The difficulty of maintaining a truly uniform velocity and acceleration in real life situations should also be indicated.

(k) Question how the students know that the graphs are drawn for motion in one direction only in spite of the fact that the car seen in the program is seen to turn around.

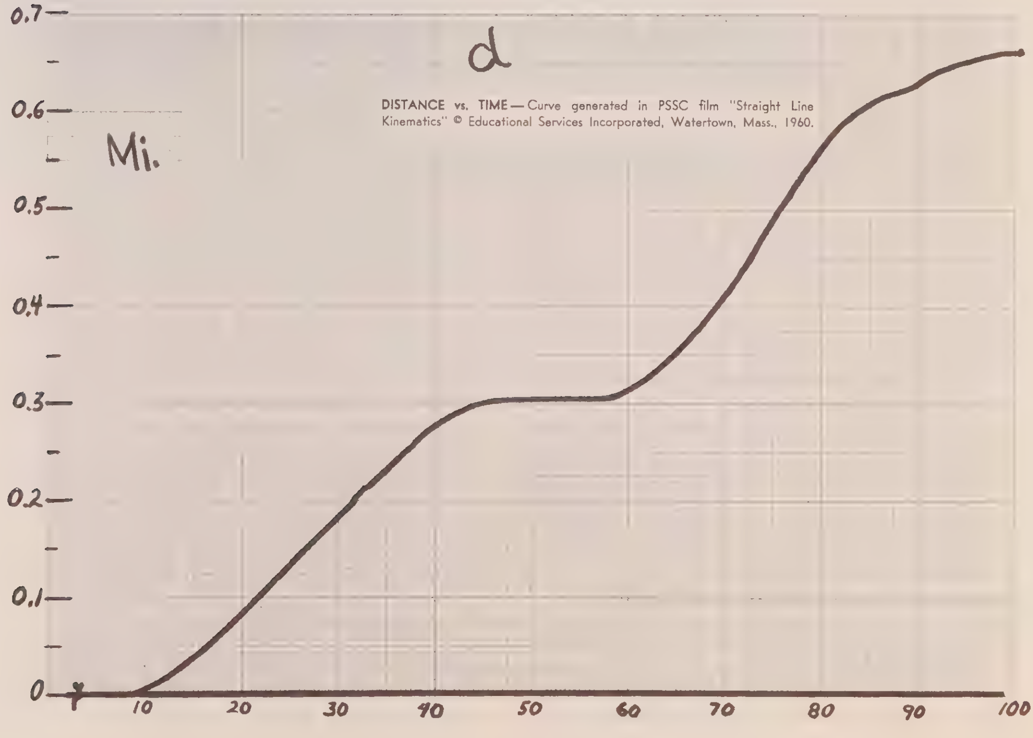
FURTHER SUGGESTED ACTIVITIES

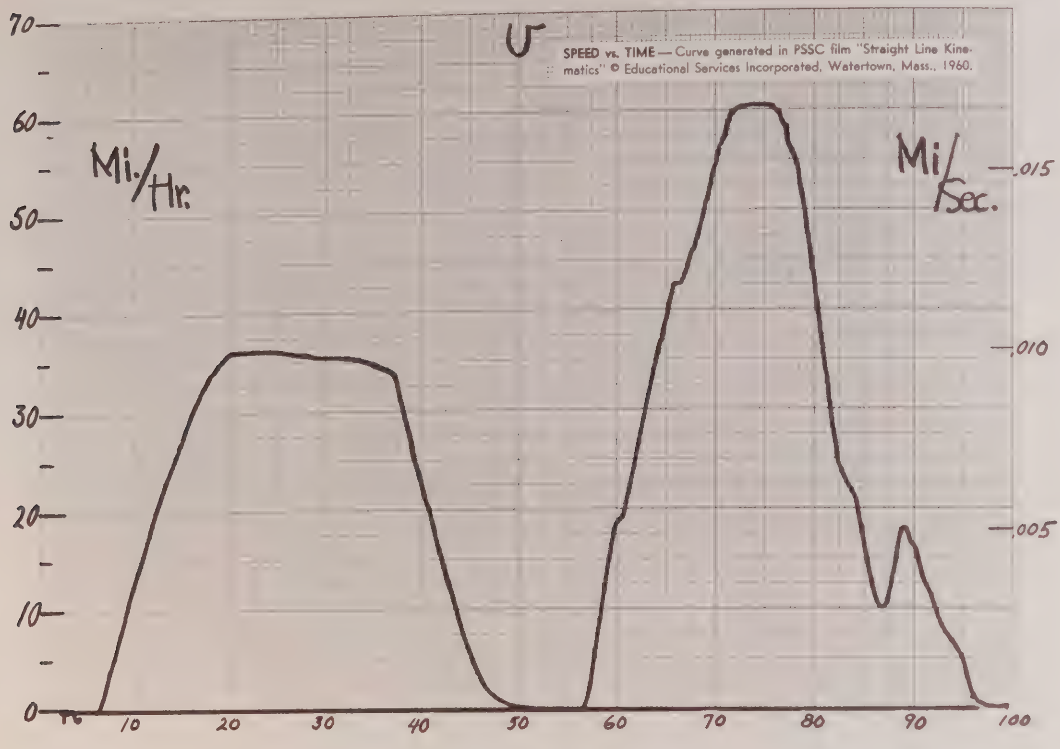
Before questioning the students further on the actual graphs used in the broadcast it might be advisable to work with a graph which is less complicated. Such a graph follows on p.4. In this case, the v – t graph is given and it is required that the d – t and a – t graphs be drawn as accurately as possible.

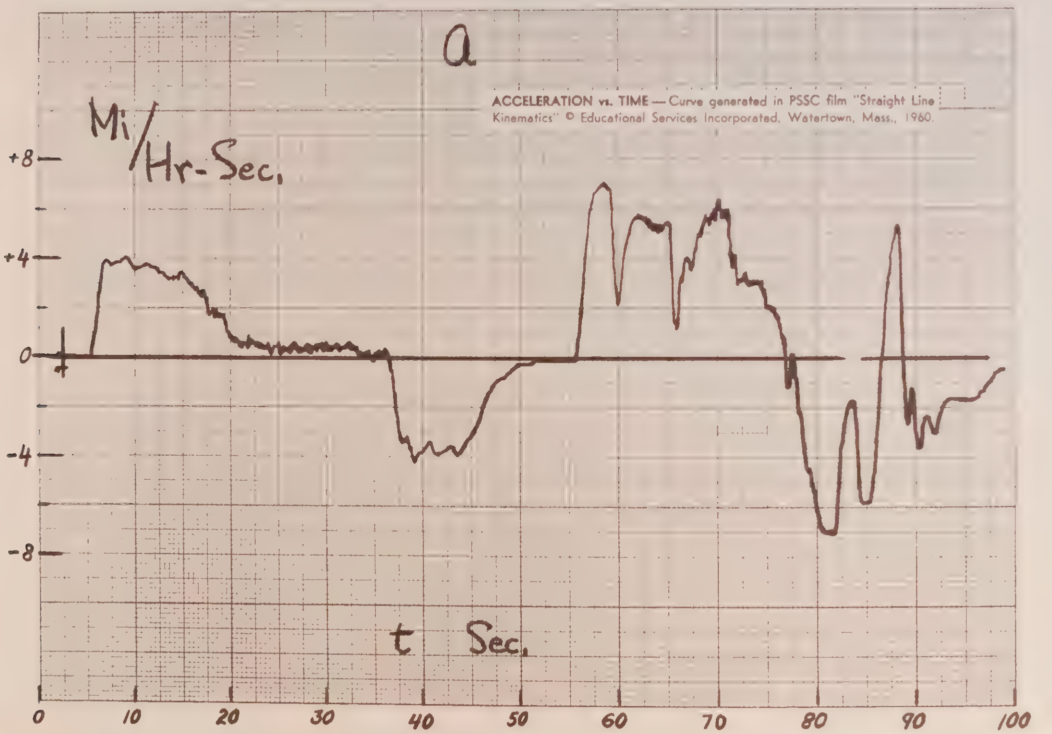
NOTE: These graphs may be purchased in quantities for class use from the following:

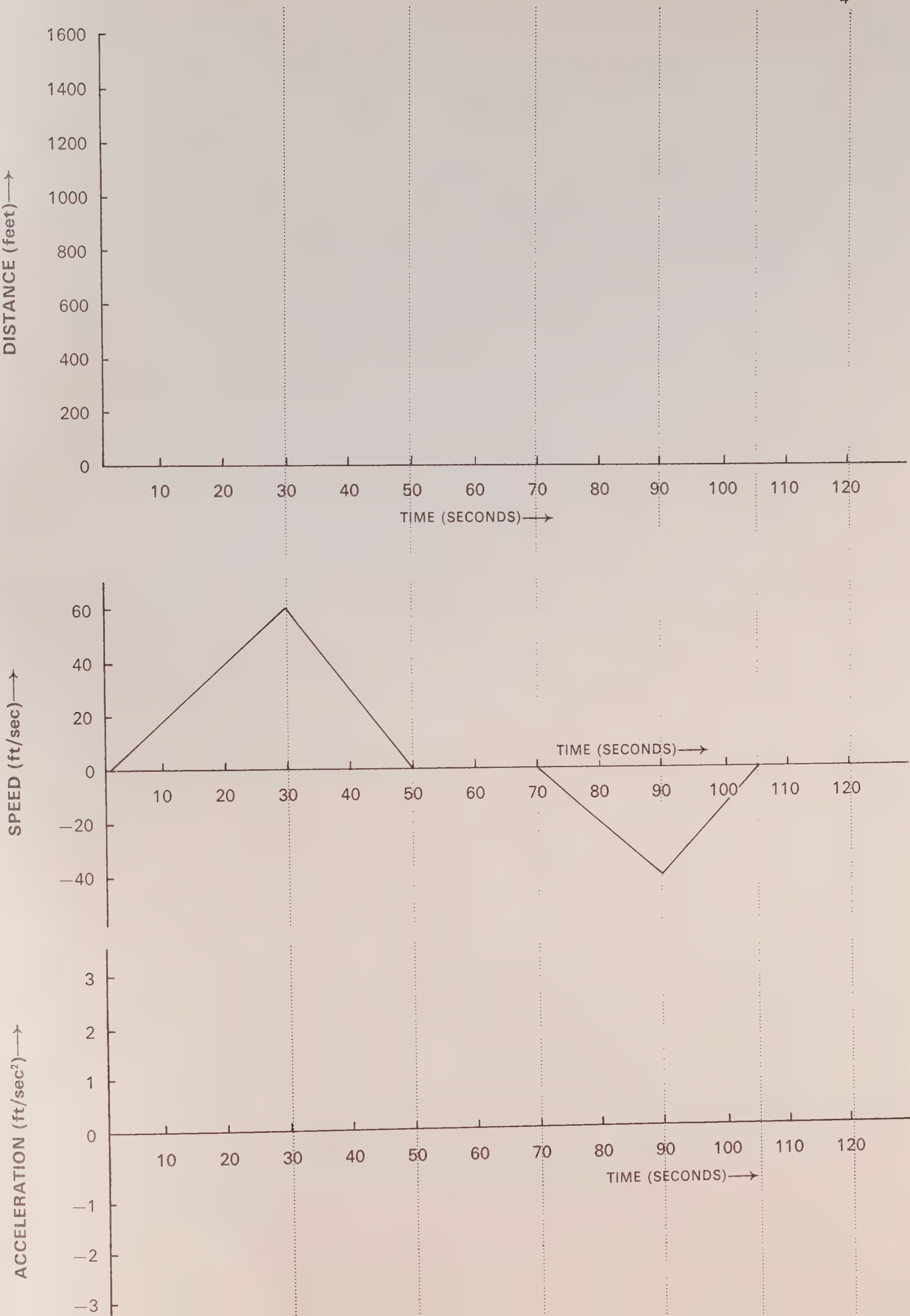
(a) Stark Electronics, Ajax, Ontario, or

(b) Canadian Laboratory Supplies Ltd., 80 Jutland Road, Toronto, Ontario. (Telephone 255-5501).

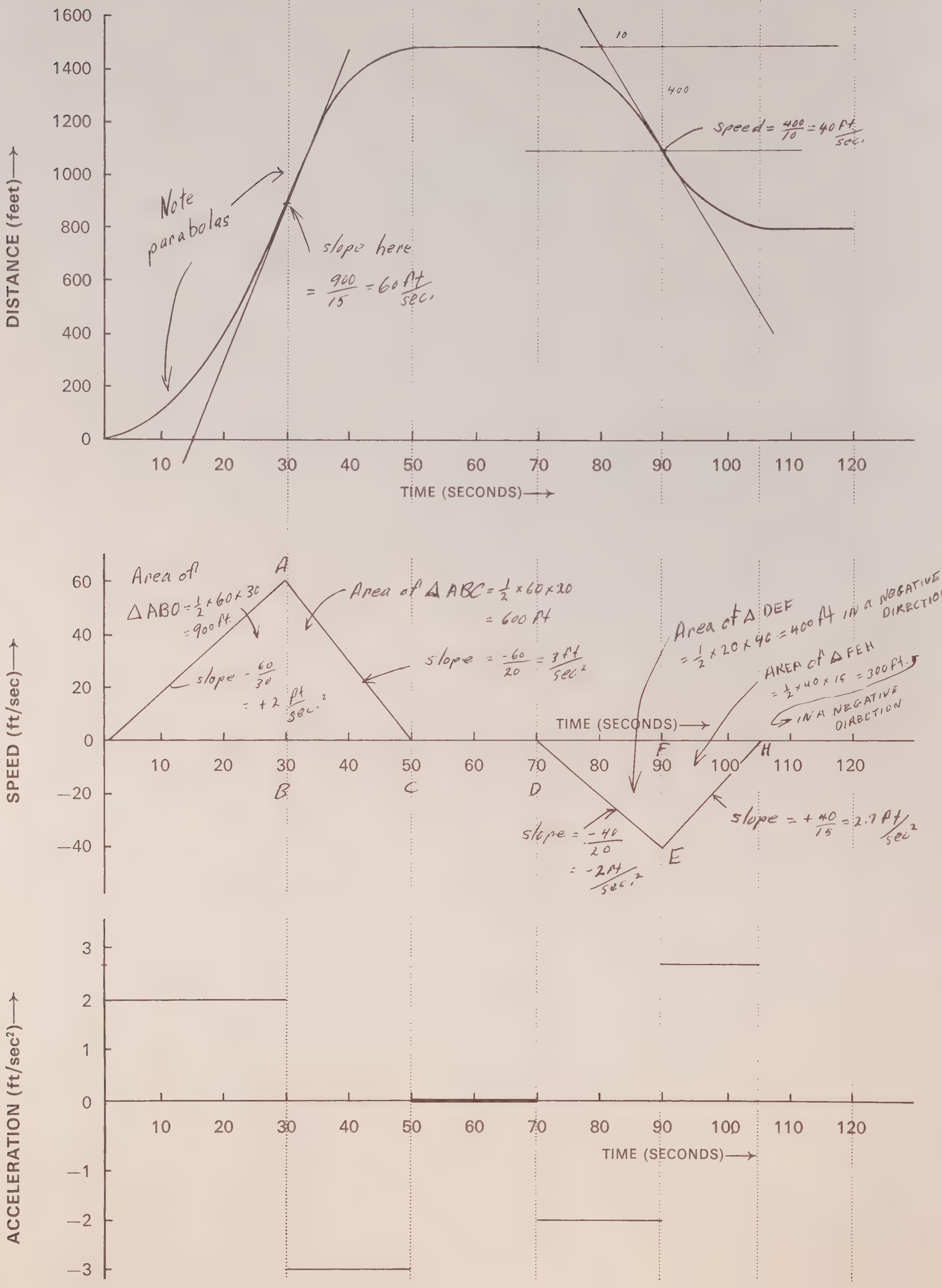



v
SPEED vs. TIME — Curve generated in PSSC film "Straight Line Kinematics" © Educational Services Incorporated, Watertown, Mass., 1960.
Mi./Hr.
Mi/Sec.
70
60
50
40
30
20
10
0
.015
.010
.005
10
20
30
40
50
60
70
80
90
100

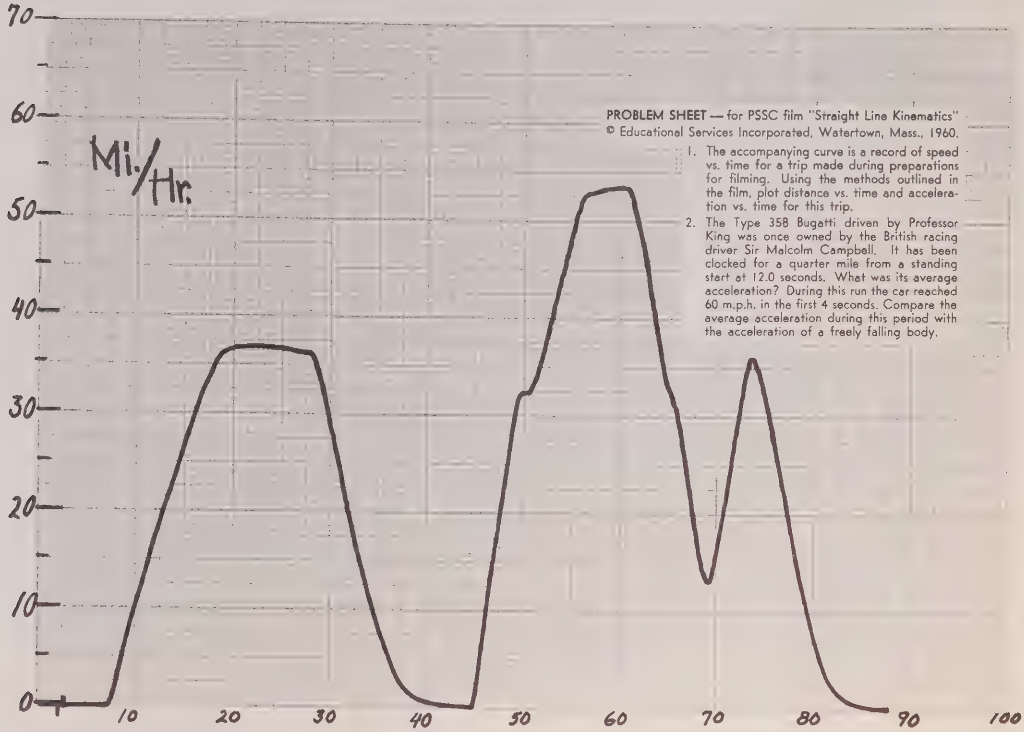

a
ACCELERATION vs. TIME — Curve generated in PSSC film "Straight Line Kinematics" © Educational Services Incorporated, Watertown, Mass., 1960.
Mi/Hr-Sec.
+8
+4
0
-4
-8
t Sec.
0
10
20
30
40
50
60
70
80
90
100


DISTANCE (feet)
1600
1400
1200
1000
800
600
400
200
0
10 20 30 40 50 60 70 80 90 100 110 120
TIME (SECONDS)
SPEED (ft/sec)
60
40
20
0
−20
−40
TIME (SECONDS)
10 20 30 40 50 60 70 80 90 100 110 120
ACCELERATION (ft/sec²)
3
2
1
0
−1
−2
−3
10 20 30 40 50 60 70 80 90 100 110 120
TIME (SECONDS)

5 The solutions are provided as follows:



It is further suggested that the following graph might be given as a further exercise.



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PROGRAM No. 2

TEACHER'S GUIDE

Optics and Waves

INTRODUCTION

Six films made by E.S.I. are available and applicable to Part II of the Grade 13 course. This area deals with the topic, Optics and Waves. The films are:

1 Introduction to Optics
2 Pressure of Light
3 Speed of Light
4 Simple Waves
5 Ripple Tank Phenomena, Part 1. (Reflection & Refraction)
6 Ripple Tank Phenomena, Part 2. (Interference and Diffraction).

One broadcast only is devoted to Part II of the Physics course and it is presented as a review program. It was decided that this was the best way to present this area of study at this time of the school year. Consequently, excerpts from several of the above-listed films have been used in this second telecast of the series. These film excerpts have been selected and put together in order to present a continuous line of thought or development as presented in Part II of the course.

MAJOR POINTS OF INTEREST IN THE PROGRAM

1 Observe the various ways light behaves. These include:
(a) rectilinear propagation
(b) diffraction
(c) interference patterns
(d) non-interaction of intersecting light beams
(e) scattering
(f) reflection
(g) partial reflection and partial transmission at the boundary of a transparent medium
(h) refraction

2 On the basis of this observed behaviour, a theory or a model of light is established, namely, the simple particle theory as propounded by Sir Isaac Newton.

3 This particle theory is then used to predict certain other behaviour patterns which are found to be true.

4 Some difficulties which the theory encounters are discussed.

5 In the search for a more adequate model, the behaviour of waves is investigated by the use of water waves in a ripple tank. The following behaviour of waves is observed:
(a) reflection
(b) refraction
(c) dispersion
(d) diffraction — which gives a clue to the wavelength of light waves
(e) interference — emphasis is placed on this study to establish a way of measuring the wavelength of waves.

The interference of waves from two point sources is carefully analysed. The dependence of the spread of the interference pattern on variations in source separation and wavelength is particularly noted.

From the formula $\frac{(n-\frac{1}{2})\lambda}{d}=\frac{x}{L}$ for finding the wavelength is developed. The adaptation of this formula into the form $\Delta X=\frac{L\lambda}{d}$ is easier to use in practice.

6 The effect on the interference pattern of changing the phase relationship between the sources is noted.

7 The device of using diffraction at a narrow slit to produce a new source of circular waves and therefore of using two slits in the path of waves *from a single source* to provide two sources in phase is illustrated as the method to obtain *two sources* of light waves which are in *phase*. This observation leads directly to Young's experiment.

8 Caution is needed in arriving at a definite conclusion as to which is the *correct* theory.

POINTS FOR FURTHER AMPLIFICATION AND DISCUSSION

1 It must be remembered that the "fuzziness" usually seen at the edges of shadows is the result of the source of light not being a point source. The picture of the needle in the film segment of the broadcast was taken with a source having a diameter of .15 millimetres. It can therefore be assured that most of the "fuzziness" is caused by diffraction.

2 The word "diffraction" is used in the broadcast program in the sense of *bending* around the edge of an obstacle. Since the term is often used in textbooks to include the interference effects accompanying diffraction, it was necessary to establish this distinction.

3 Broadcast time did not allow for an explanation of diffraction on the basis of Huygen's Principle. Nor was it possible to follow this with an explanation of the interference pattern seen with diffraction with a single slit. Time also did not allow for specific reference to the interference bands observed with the needle. In connection with the pattern observed with the needle, interference bands were seen around the outside of the needle and inside the dark region behind it.

The full explanation of these bands is too complicated for study at this stage. A satisfactory explanation, however, may be found in the textbook, *Physics* by McKay and Ivey published by Ryerson.

Students should be made aware that when a double slit interference pattern is seen, each of the slits is producing its own single slit pattern. The single slit pattern may be described as follows — plotting intensity of light versus distance from the centre. (See Figure 1).

If two of these slits are placed side by side, they each produce single slit diffraction.

Because the two slits are very close together, the two single slit diffraction patterns will be superimposed. This, however, means that there will be interference between the light from the two slits and hence the double slit interference pattern is produced. Note that the double slit interference pattern will occur inside the single slit pattern as indicated in Figure 2.

NOTE: These effects can be seen very clearly in the film loops entitled, *Single Slit Diffraction* and *Double Slit Diffraction*. These film loops are two of the Miller Series which are distributed by The Ealing Corporation, Cambridge, Mass., U.S.A.

In practice, when one wishes to use the double slit diffraction pattern to find the wavelength of light, very narrow slits are used so that the single slit pattern is very broad, and only the centre maximum (zero order maximum) of the single slit pattern can be seen. In this way, there is no confusion between the single and double slit interference patterns. This is illustrated in Figure 3.

4 Pressure of light may also be explained by a wave theory. Students should not be left with the idea that only the particle theory predicts pressure of light.

5 In the apparatus used to demonstrate pressure of light, very careful electrostatic shielding was necessary. This shielding was achieved by coating the inside of the evacuated glass tube with a very thin, transparent layer of metal. This fact is mentioned here because further reference will be made to these facts in the film segment on Forces which will be included in the next program.

6 The pressure of 3×10^{-9} atmospheres quoted by Professor Zacharias for the pressure of light refers only to the pressure exerted by light from the 20 watt lamp when it was *focussed* on to the foil. Later, in the film segment, the professor quotes the pressure of sunlight as 3×10^{-11} atmospheres.

It might be a good exercise for students to convert this reading to pounds per square

FIGURE 1

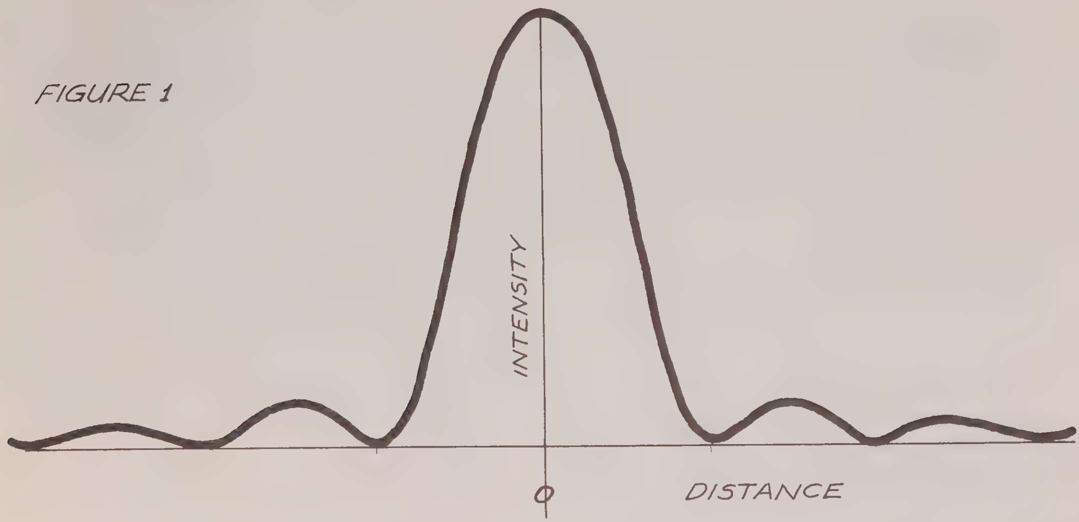


FIGURE 2

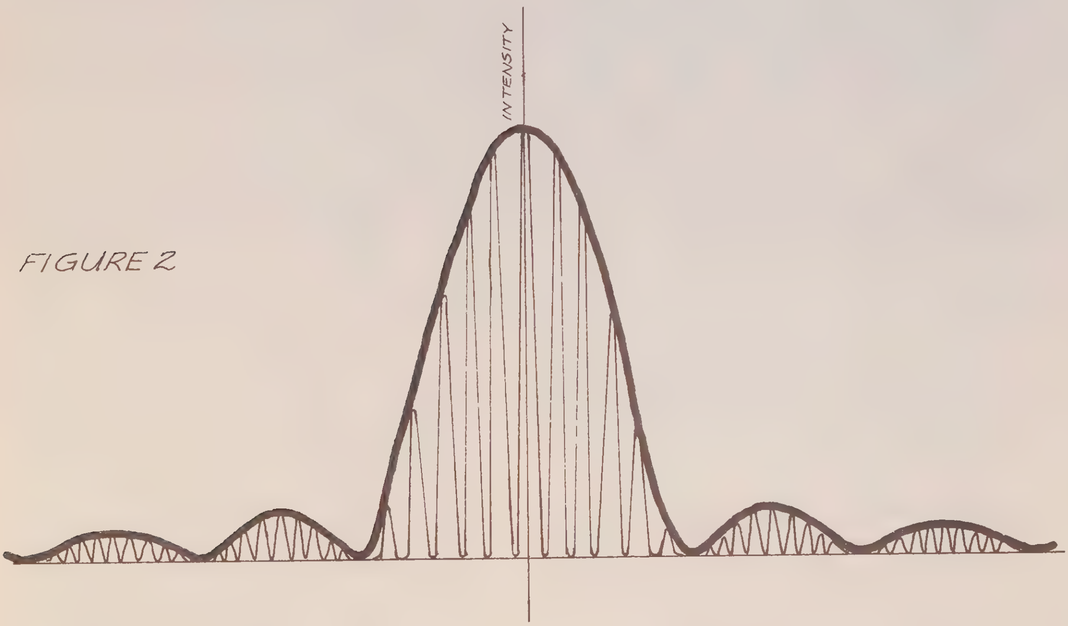
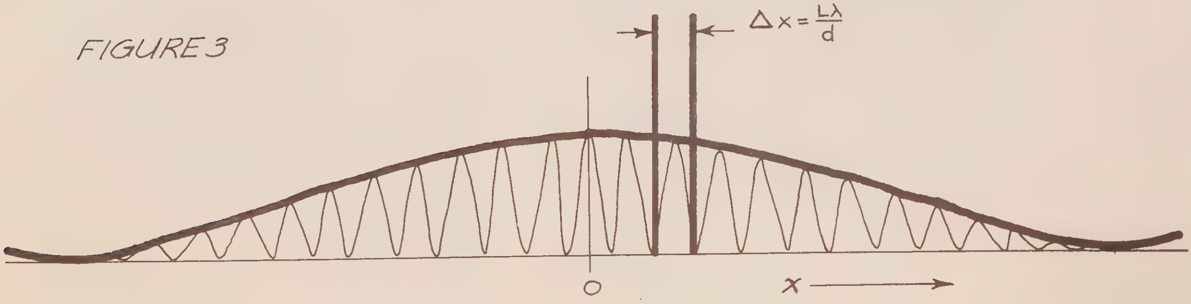


FIGURE 3



mile so that they will better appreciate its magnitude:

$$1 \text{ atmos.} = 15 \frac{\text{lb.}}{\text{in.}^2}$$

$$= 15 \times \frac{(12 \times 5280)^2}{1} \left\{\frac{\text{lb.}}{\text{in.}^2}\right\} \times \left\{\frac{\text{in.}^2}{\text{ft.}^2}\right\} \times \left\{\frac{\text{ft.}^2}{\text{mi.}^2}\right\}$$

$$= 6 \times 10^{10} \frac{\text{lb.}}{\text{mi.}^2}$$

$$\therefore 3 \times 10^{-11} \text{ atmos.} = 3 \times 10^{-11} \times 6 \times 10^{10} \frac{\text{lb.}}{\text{mi.}^2}$$

$$= 1.8 \frac{\text{lb.}}{\text{mi.}^2} \text{ very nearly.}$$

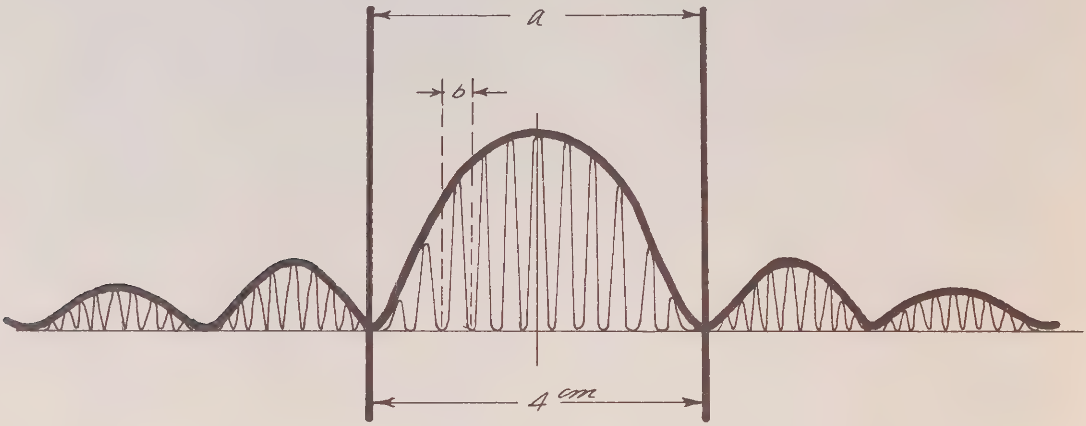
7 It should be established that Professor Zacharias is using the phenomenon of resonance to magnify the very small force of light on the foil.

FOLLOW-UP PROBLEMS

There are excellent questions on this section of the course in the P.S.S.C. objective tests, series O and series N. These could easily be adapted to the "essay-type question" if desired.

An example of such a question on single and double slit interference pattern follows:

The diagram represents an intensity pattern formed by a double slit. The pattern was obtained by using monochromatic light of wavelength 5 x 10^{-5}cm. The source was located 4 meters from the double slit.



(i) If the slit width and the separation are maintained, and the wavelength is increased, what would happen to the dimensions 'a' and 'b' in the above pattern?

(ii) If the slit separation is increased while the original slit width and wavelength are maintained, what would happen to the dimensions 'a' and 'b' in the above pattern?

(iii) What is the slit separation of the apparatus that would produce the interference pattern shown above?

ANSWERS:

(i) a and b—both *increase*

(ii) a—unchanged
b—decreased

(iii) $\Delta X = b$

$\therefore 9\Delta X = 4$ cm

$$\Delta X = \frac{4}{9} \text{ cm}$$

$$\Delta X - \frac{L\lambda}{d}$$

$$d = \frac{L\lambda}{\Delta X} \quad \left\{ \begin{array}{l} L = 4\text{m or } 400 \text{ cm} \\ \lambda = 5 \times 10^{-5} \text{ cm} \\ \Delta X = \frac{4}{9} \text{ cm} \end{array} \right.$$

$$d = \frac{400 \times 5 \times 10^{-5}}{\frac{4}{9}} \quad \frac{\text{cm} \times \text{cm}}{\text{cm}}$$

$d = 45 \times 10^{-3}$ cm
$d = \ 5 \times 10^{-3}$ cm

ontario educational television

PROGRAM NO. 3

TEACHER'S GUIDE

Forces

INTRODUCTION

This program is intended as a general introduction to Part 3 of the Physics course. It, however, also includes some ideas from Part 4 of the Physics program in order to emphasize the fundamental importance of the study of forces within the total physics course. Since it is likely that many teachers will have taught the work on the topic, Universal Gravitation, by the time this program is telecast, it was decided to place a little more emphasis on the Cavendish experiment than is included in the film section used in this broadcast.

MAIN POINTS OF THE BROADCAST

(a) Such experiences as speeding up, slowing down, changing direction, deformation of shape, elasticity and breaking, give intuitive concepts as to the nature of forces.

(b) The peculiarity of the meaning of such a statement that one object pushes on another because it is in "contact" with it, is mentioned. It is explained in the program that when such a statement is made, it is because our observation is not sufficiently refined. If, however, things are examined more closely, it will be found that these so-called contact forces are still action-at-distance forces, although the distances are measured on an atomic scale.

(c) Although there appears to be a very wide variety of types of forces in nature, actually all can be reduced to three basic types: gravitational, electrical (or electromagnetic), and nuclear. In addition, all of them share the common property of being dependent on the distance between the bodies involved.

(d) The Cavendish experiment is performed to show the universal nature of gravitational attraction. In addition, the fact that gravitational forces are very weak compared to electrical forces is demonstrated.

(e) Other differences between electrical and gravitational forces are also mentioned. Furthermore, magnetic forces are introduced at this time. It is important to realize that magnetic forces are not independent of electrical forces. They occur with electrical charges in motion.

(f) Attention is drawn to the magnitude of nuclear forces.

(g) It is also stated that when scientists begin a study of a complex nature, they invariably study a very simple situation first.

Following the film segment of the program, three points are given special emphasis.

(i) When Professor Zacharias writes down the three types of forces as gravitational, *electrical,* and nuclear, the word *electrical* is meant to include both electrostatic and magnetic forces and might best be stated as 'electromagnetic' forces. As the professor does not make this point, it subsequently needs to be emphasized.

(ii) With regard to the magnitude of the forces illustrated in the Cavendish experiment, it is suggested that the students, before the broadcast, might make their own estimations of the various values needed to calculate the forces, and then compare their estimations with those in the program. It is pointed out that the latter were obtained purely by estimates made while watching the film segments. The 'teacher-presenter' had no previous 'inside information'. It was con-

sidered to be a worthwhile exercise in estimation to an order of magnitude.

Mass of bottle of water, $m_1 = 1$ kg.
Mass of box of sand, $m_2 = 50$ kg.
Distance between their centres, $R = 9$ inches or .23 m.
The students should be reminded that although the formula $F = \frac{Gm_1m_2}{R^2}$ only applies to spheres or to point masses, yet for other shapes, the value it gives is certainly correct to well within the order of magnitude, (i.e. a factor of 10). It is also definite that the other estimates are correct within a factor of 2. As a result it is felt that the statements made in the telecast are reliable.

Since $G = .667 \times 10^{-10} \frac{m^3}{kg.-sec^2}$

$$\text{Therefore } F = .667 \times 10^{-10} \times 1 \times \frac{50}{(.23)^2}$$

$$\frac{m^3}{kg-sec^2} \times kg \times \frac{kg}{m^2}$$

$$\text{or } F = 6 \times 10^{-8} \ \frac{kg-m}{sec^2} \text{ (or newtons)}$$

Therefore the gravitational attraction lies between 10^{-8} and 10^{-7} newtons.
The electrical force is estimated by using $F = ma$, assuming, approximately, uniform acceleration. It will be observed that Professor Zacharias, in the film, attempted to keep the rod at a constant distance from the bottle of water.
To obtain "a", it was estimated that the bottle moved a distance of 8 cm. or .08 m. from rest in a time of 2 seconds.

Therefore using $d = \frac{1}{2} at^2$, $.08 = \frac{1}{2}a(2)^2$,
$a = .04$ m/sec^2
Therefore using $F = ma$, where m is the mass of the bottle of water

$$F = 1 \times .04 \ \frac{kg-m}{sec^2}$$

$$\text{or } F = 4 \times 10^{-2} \text{ newtons}$$

It must also be realized that one errs on the small side of these electrical forces. It is stated in the program that $F = 10^{-2}$ newtons and so, even for this smaller estimate of the electrical force

$$\frac{F \text{ (electrical)}}{F \text{ (gravitational)}} = \frac{10^{-2}}{10^{-7}} \text{ or } \frac{10^{-2}}{10^{-8}}$$

This means that the electrical force is from 100,000 to 1,000,000 times greater than the gravitational force.

This leads to the third point to be emphasized.

(iii) If the electrical force is this much greater than the gravitational, it is the electrical force of repulsion which dominates when one object is very close to another. Since electrical forces vary inversely as the square of the distance between the bodies involved, it must be considered how large they must become at a distance of even 10^{-4} cm. Hence, the concept of a "contact" force being still an "action-at-distance" force. Consequently, when it is stated that one thing touches another, it is just that the electrical force of repulsion has reached a certain magnitude.

ADDITIONAL POINTS FOR DISCUSSION

1 Professor Zacharias discusses a single force acting on a single object. When he states this, he is making two assumptions:
(a) He is ignoring the force of gravity down and the force of the table up. There, of course, are balanced forces and therefore, the situation is the same as if they did not exist. This is also the approach taken in the textbook.
(b) It should be stated that it is impossible to exert a force without involving two bodies. The simple situation of considering only a single force on a single object is therefore the limiting case in which the other body involved is so large that we can ignore its effect. For example, in experiments III—2, 3 when the cart is pulled with the elastic bands, we completely ignore the effect on the earth.

2 Students should be made aware that the statement '*nuclear forces*' refers to the forces connected with only the nucleus of the atom and that it is *not* a general reference to all forces involved within atoms.

3 Although all the types of forces are dependent on the distance between the bodies involved, this does not mean to say that they are only distant-dependent. Other factors such as velocity may affect the forces.

4 In connection with the Cavendish experiment, a copy of his original paper may be found in the publication, 'Scientific Memoirs, The Laws of Gravitation', edited by Stanley Mackenzie, American Book Company, 1900. This book is probably available in most of the larger reference libraries.

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PROGRAM No. 4

TEACHER'S GUIDE

Inertia and Inertial Mass

INTRODUCTION

This fourth program of the series *Macrocosms and Microcosms* is designed to review sections 20-1 to 20-6 of the P.S.S.C. text. It also relates to laboratory experiments III—2, 3, and 4. Segments of the two P.S.S.C. films, *Inertia,* and *Inertial* Mass are included in this program.

MAIN IDEAS PRESENTED IN THE PROGRAM

1 Motion is everywhere. There are different types of motion.

2 What causes motion? It is obvious that any change in motion requires a force. Does constant motion require a constant force?

3 A demonstration of an object moving with no force is presented. (A dry-ice puck on a horizontal sheet of plate glass. After the initial push, there is no force on it to cause acceleration or retardation).

Motion in a straight line at constant speed is observed. Conclusion: Galileo's Law of Inertia has been demonstrated to be true within the limits of experimental uncertainty.

4 If a constant motion results from no force, what is the effect of applying a single constant force? A discussion of the method used to apply the constant force is presented, followed by a demonstration and an analysis of the resulting motion. (Constant force produces constant acceleration).

5 The effect of changing the force is shown. In the film segment, the lecturer, Dr. Purcell, doubles the force and finds that 2F produces 2a. He then makes a generalization on this, $\Delta v \propto F$ for the same Δt, or $\alpha \propto F$.

6 A recapitulation of the above ideas is then presented and the program continues with a segment from the film, *Inertial Mass,* in order to present the remaining concepts.

7 What is the effect of applying the same force to different objects? How is inertia measured? One dry-ice disc is chosen as a "standard object" and one rubber ring stretched to a given amount is used as a "standard force". A measure of the inertia of this "standard object" is found by measuring the acceleration produced by the constant force. It is 6.1 cm/sec.^{2}

8 A different object is presented by fastening two identical dry-ice discs together. The same "standard force" is applied and the resulting acceleration is 3.1 cm/sec.^{2} Since this is half the value obtained with one disc, *and if we assume that inertial masses are additive,* we may state that this experiment suggests that acceleration produced by a "standard force" is inversely proportional to the inertia of the body. This presents a method of comparing inertias.

9 Two very dissimilar objects such as a dry-ice disc and a pile of books may have the same inertia. This is checked by measuring the acceleration produced by the "standard" force. For two discs the acceleration is 3.1 cm/sec.^{2} for one disc plus a pile of books, the acceleration is 3.2 cm/sec.^{2}

10 The next demonstration in the program illustrates how to 'measure' the inertia of another

different object (in this case, a dictionary is used), by comparing it with the inertia of the "standard object". The acceleration of the disc plus dictionary is 4.2 cm/sec.^{2}

$$\text{Since } a \propto \frac{1}{\text{Inertia}}$$

$$\frac{\text{Inertia of disc+dictionary}}{\text{Inertia of disc}} = \frac{\text{Acceleration of disc}}{\text{Acceleration of disc + dictionary}} = \frac{6.1}{4.2} = \frac{1.45}{1}$$

However, because the disc represents the "standard object", it has one unit of inertia.

Therefore, using the theorem if $\frac{a}{b} = \frac{c}{d}$, then

$$\frac{a-b}{b} = \frac{c-d}{d}$$

$$\text{Then, } \frac{\text{Inertia of dictionary}}{\text{Inertia of disc}} = \frac{.45}{1}$$

Therefore, Inertia of dictionary is .45 units.

11 To re-emphasize that entirely different objects can have the same inertia, a bag of potatoes and the dictionary are each placed on identical discs and pulled with the same force. Since each travelled the same distance in the same time, it is concluded that their accelerations are the same and therefore, their inertias are the same. At this time, the terms 'mass' and inertial mass (m_i) are introduced as alternatives to the term, inertia.

12 In the film segment, Dr. Purcell, the narrator, summarizes all the experiences so far gained, by the statement $a = \frac{kF}{m_i}$, where the value of the proportionality constant k depends only on the choice of the units for a, F, and m_i.

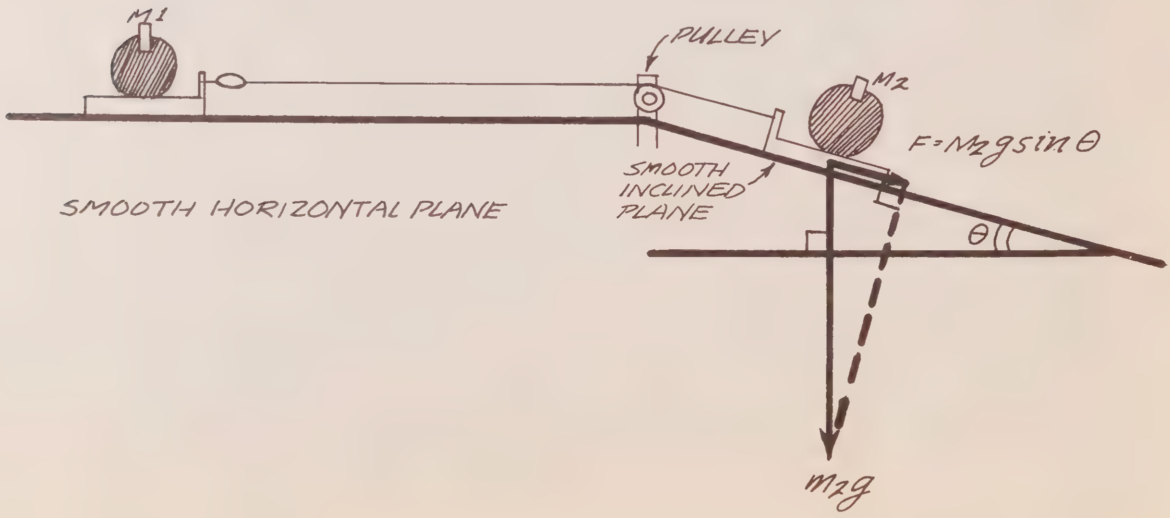
13 The bag of potatoes plus the dictionary which are now known to have the same inertial mass are shown also to possess the same gravitational mass. The fact that there are different physical quantities because there is no connection between the way in which each is measured is emphasized. The fact that inertial mass is proportional to gravitational mass is a result known purely from experiment.

ADDITIONAL POINTS FOR DISCUSSION AND FOR INFORMATION

1 Professor E. M. Purcell shared the 1952 Nobel Prize in Physics with Professor F. Bloch for his work in nuclear magnetic resonance. Purcell and Bloch were however, working quite independently.

2 It should be realized that when it is stated that the object moves under the action of *no* force, only forces acting along a horizontal surface are being considered. This is merely adopting Galileo's method of reasoning. There is, of course, *no* place in the universe where an object could exist with *no* force on it. This is the reason why the idea of *no unbalanced force* must be introduced for the general statement of the Law of Inertia.

3 Professor Purcell's "trained assistant" in the program is another dry-ice puck sliding down a smooth inclined plane. Because an understanding of how this "trained assistant" operates is needed and is of interest to students, the following discussion is outlined.



The force, F, which is causing the acceleration is the component of m_2g along the ramp, which equals $m_2g\sin\theta$

Because m_2g is a constant force, and θ is constant, then, if the plane is smooth $m_2g\sin$ is constant.

But F is accelerating both m_1 and m_2

$\therefore \quad F=(m_1+m_2)a$

or $\quad (m_1+m_2)a=m_2g\sin\theta$

hence $\quad a=\dfrac{m_2g\sin\theta}{m_1+m_2}$

In order to double F one also has to double a. The easiest way to do this is to do what Professor Purcell did in the film, that is, to double $\sin\theta$.

On the film segment of "Inertial Mass", the same arrangement is used to provide a constant force. Professor Purcell indicated when he referred to his "assistant" that the puck m_2 was the same as the puck m_1.

If, for simplicity, it is assumed that $m_2=m_1$:

Then $a=\dfrac{m_1g\sin\theta}{m_1+m_2}=\dfrac{1}{2}g\sin\theta$

When, however, two discs are tied together in order to see the effect of applying the *same force to a different object,* note that the *exact* same arrangement could not be used to pull the new object, because now there would be a different acceleration and hence a different force.

$$a^1=\frac{m_2g\sin\theta}{2_1m+m_2}=\frac{m_1g\sin\theta}{3m_1}=\frac{1}{3}g\sin\theta$$

Therefore, the force on a single disc, m_1, is $F=m_1a=\frac{1}{2}m_1g\sin\theta$, whereas the force on the double disc is $F_1=2m_1a_1=\frac{2}{3}m_1g\sin\theta$, which is *greater.*

It is, however, known that the force on $2m_1$ as shown in the film *is* the same, because the elastic band is stretched to the same amount. In order to accomplish this, $\sin\theta$ must have been reduced for the second demonstration.

4 It should be clarified that the method used to find the acceleration presented in the films is valid only for uniform acceleration. It is only in the case of uniform acceleration that average velocity equals instantaneous velocity at the middle of the time interval. Therefore, substracting the average velocities over successive one second intervals is the same as substracting two instantaneous velocities at a time interval of one second. In addition, the above gives an average acceleration, but since the acceleration is uniform, the average acceleration equals the instantaneous acceleration of any instant.

5 It is interesting to note how frequently one assumes the additive nature of physical properties as so-called, common-sense rules without proving them. In the first part of the program the additive nature of the independent forces of the two rubber bands is assumed. Furthermore, in the film segment on 'Inertial Mass', the additive nature of inertia is assumed. Note, however, that the *one* experiment could not prove (a) that inertia is additive and (b) that acceleration is inversely proportional to inertia. One, therefore, assumed that the two inertias were additive. Students should be advised not to assume statements without checking. For example, it may be shown that the addition of volumes does not always hold because 50 cc. of water plus 50 cc. of alcohol only produces approximately 96 cc. of solution.

6 It should be emphasized that inertia has been measured without reference to units of force. All that is necessary is to have a standard object (m_2) as a unit of inertia, and compare the inertia of any other object (m_1) with it by means of the relationship, $\frac{m_2}{m_1}=\frac{a_1}{a_2}$, using the same "standard" force for all experiments.

The students might be given other problems on finding inertia without being told the force, because this gives them a better idea as to the meaning of inertial mass. For example, a certain force gives a mass m_1, an acceleration of 8m/sec^2, and a mass m_2, an acceleration of 24m/sec^2.

(i) If m_1 is taken as a standard mass, what is the mass of m_2?

(ii) What acceleration would the same force give m_1 and m_2 when they are fastened together?

(i) **Solution**

$$\frac{m_2}{m_1} = \frac{a_1}{a_2}$$

$$\frac{m_2}{m_1} = \frac{8}{24}$$

Therefore, $m_2 = \frac{1}{3} m_1$

For example, if $m_1 = 1$ kg. then $m_2 = \frac{1}{3}$ kg

(ii) **Solution A**

Let the acceleration of $m_1 + m_2$ be a_3 m/sec$_2$

$$\frac{m_1 + m_2}{m_1} = \frac{a_1}{a_3}$$

Using the result of (1) $\dfrac{m_1 + \frac{1}{3} m_1}{m_1} = \dfrac{8}{a_3}$

Therefore $\frac{4}{3} = \frac{8}{a_3}$

$$a_3 = 8 \times \frac{3}{4} = 6$$

Therefore, $m_1 + m_2$ would be given an acceleration of 6 m/sec.$_2$ by the same force.

(ii) **Solution B**

It is worthwhile to note another solution which does not use the intermediate step of part (i).

$$\frac{m_2}{m_1} = \frac{8}{24}$$

Using the theorem, if

$$\frac{a}{b} = \frac{c}{d}, \text{ then } \frac{a+b}{b} = \frac{c+d}{d}$$

$$\frac{m_1 + m_2}{m_1} = \frac{32}{24}$$

This states that when m_1 has an acceleration of 32 units, $m_1 + m_2$ has an acceleration of 24 units for the same force. But we are interested in a force which gives m_1 an acceleration of 8 units.

Therefore $\dfrac{m_1 + m_2}{m_1} = \dfrac{32 \times \frac{1}{4}}{24 \times \frac{1}{4}} = \dfrac{8}{6}$

Therefore, the force which gives m_1 an acceleration of 8 m/sec.$_2$ will give $m_1 + m_2$ an acceleration of 6 m/sec.$_2$. In conclusion, *any quantitative information about the force is not needed.*

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PROGRAM No. 5

TEACHER'S GUIDE

Frames of Reference

INTRODUCTION

In the realm of kinematics we may use any frame of reference we wish to describe the motion of an object. It is usual to select the frame of reference which gives the simplest description of motion. This program, however, will indicate that this cannot be done when attempting a dynamical description of motion. Our laws of motion do not apply in all frames of reference.

As the whole P.S.S.C. film is shown in this program, little time is left for any other comments. Students, however, should be encouraged to make notes during the broadcast and bring them to class for discussion. On the other hand, the students might be given a list of the major points of the program in advance of the broadcast and suggest that they might wish to look for them during the viewing of the telecast.

MAJOR POINTS OF INTEREST

The following is a list of demonstrations and important ideas represented in the program:

1 All motion is relative. When an object is moving, it is usually thought of as moving relative to something else which is "fixed". Since motion is a vector quantity, it must be described relative to a "frame of reference" which consists of a co-ordinate system having x, y, and z axes. Furthermore, the frame of reference is attached to the so-called 'fixed' object. For example, in most of our normal experiences of motion we use a frame of reference attached to the earth.

2 A steel ball is dropped from an electromagnet which is at rest, relative to a frame of reference attached to the earth. The experiment is repeated in a frame of reference moving at a constant velocity to the earth. It is viewed from an earth frame of reference and from a frame of reference attached to a moving cart. The motion of the ball appeared identical (a) when the cart was standing still and (b) when the cart was moving at constant velocity. The ball was viewed *in the frame of reference of the moving cart.*

Conclusion: All frames of reference moving at constant velocity with respect to one another are equivalent.

3 From a kinematics viewpoint one tends to put oneself in the simplest frame of reference and one does not *always* view everything from the earth's frame of reference. This point is made by observing the motion of a spot near the circumference of a rolling wheel.

4 The relationship U + V for comparing velocities in one frame of reference with those in another frame of reference is demonstrated. This formula for relative velocity does not apply at speeds approaching the speed of light.

5 The motion of the falling ball is observed in an accelerated frame of reference. The distinction between inertial and non-inertial frames of reference is outlined in the program. An inertial frame of reference is one in which Galileo's Law of Inertia is supported.

6 An accelerated frame of reference is a non-inertial frame of reference because in it, an object appears to be accelerated with *no* unbalanced force! In order to be able to use the Law of Inertia relative to a non-inertial frame of reference, the idea of fictitious forces is introduced. For example, instead of thinking of the frame of reference as being accelerated,

it is treated as if it were fixed, and it is imagined that there is a force acting on the object to cause the observed acceleration relative to the frame of reference. The direction of this fictitious force is always opposite to the direction in which the frame of reference is actually being accelerated.

7 A rotating frame of reference is also an accelerated frame of reference and therefore, a non-inertial frame of reference. The fictitious force which is introduced in the rotating frame of reference to make the law of inertia remain true is called the centrifugal force. When a rotating object is viewed in an inertial frame of reference, there is *only* the centripetal force; the centrifugal does not exist.

8 Because the earth is rotating on its axis, it must be a non-inertial frame of reference. In the earth frame of reference, the fictitious centrifugal force is only 3/100 of a newton — even at the equator. As this is so small, it is usually ignored and the earth is treated as an inertial frame of reference.

9 The Foucault pendulum is explained as the means by which it is established that the earth is rotating about its north-south axis.

FURTHER DISCUSSION AND EXAMPLES

1 It should be indicated that where the words "watch for involute now" are superimposed on the screen during the broadcast, this is not the only place where an involute may be observed. This point of indication, however, is where an involute may be seen most clearly without any distraction.

2 An involute is the path as seen in a rotating frame reference of an object moving at constant speed in a straight line in an inertial frame of reference. It is best understood by drawing it as follows:

X Y is the path of an object, A, moving at constant speed in a straight line. The observer B, is rotating about O at constant angular velocity. The positions of each in an inertial frame of reference are represented by numbers 1 to 16 as shown in Figure 1.

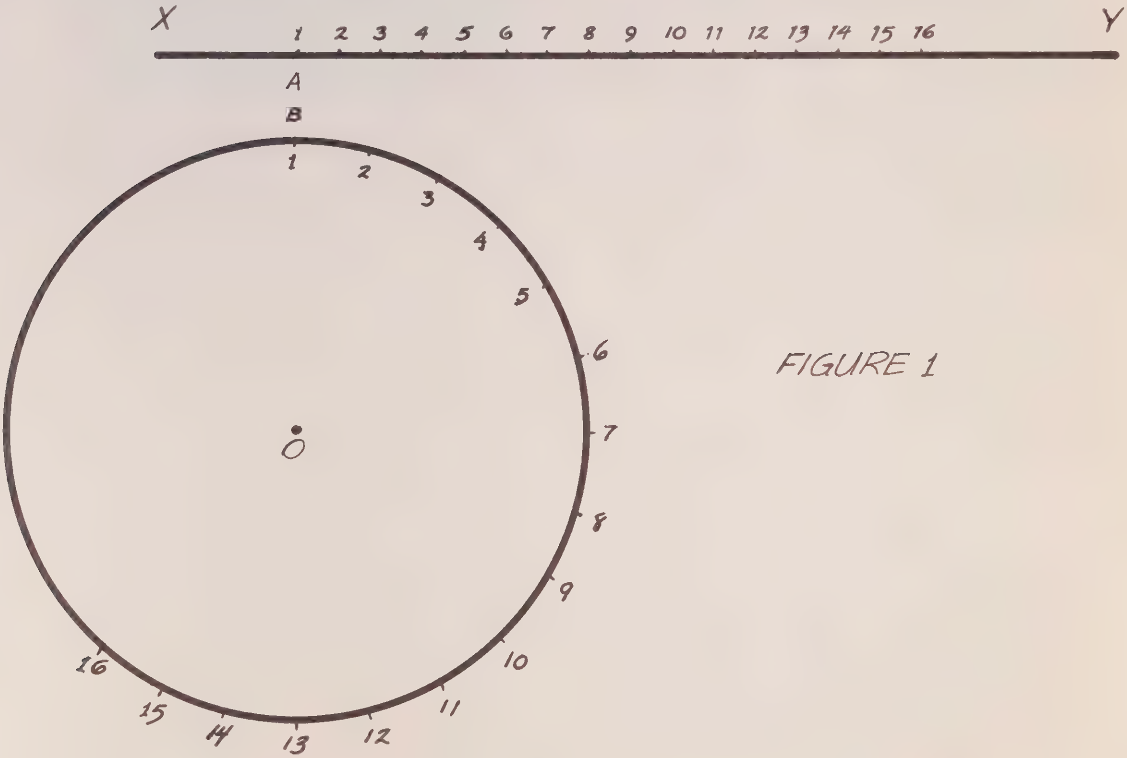


FIGURE 1

In order to see what the path of A looks like from B's point of view, position vectors must be drawn from B to A at successive equal time intervals and bring them all to a common point of origin. It must be remembered that the observer B is *not* aware of the fact that he is rotating. B believes that he is in a 'fixed' world and that only A is moving relative to him. The solution is indicated as follows in Figure 2 and Figure 3:

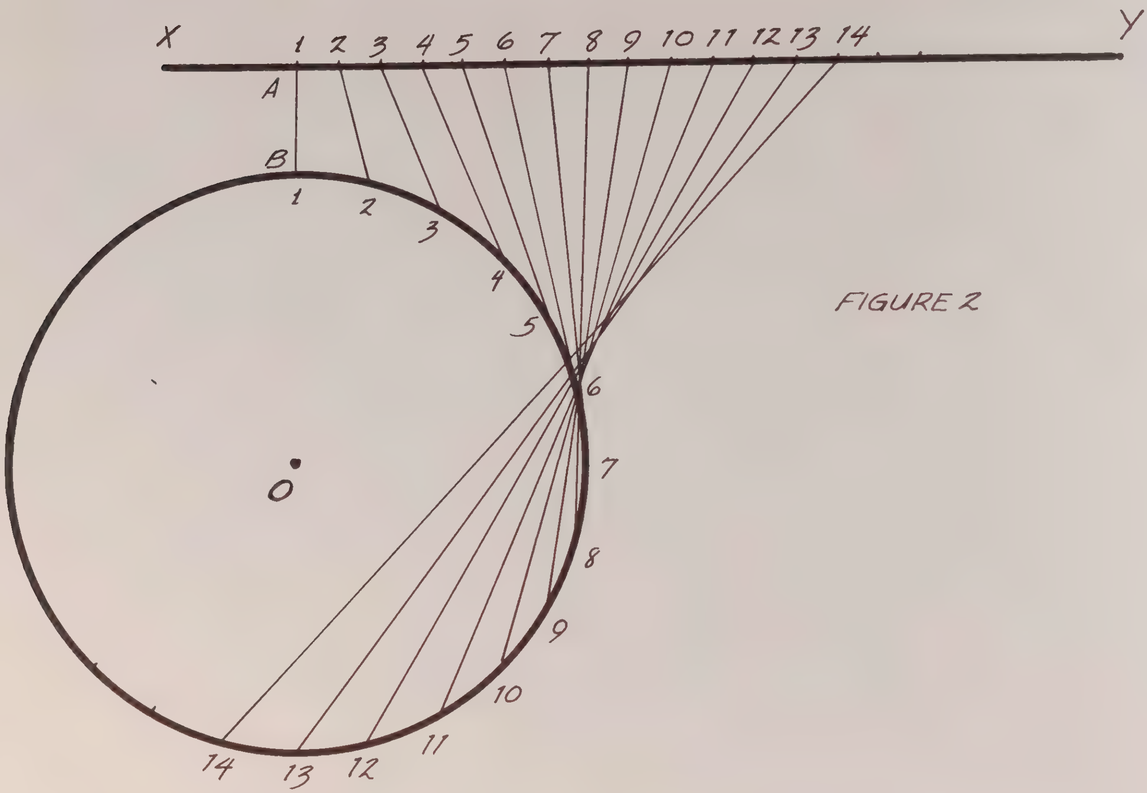


FIGURE 2

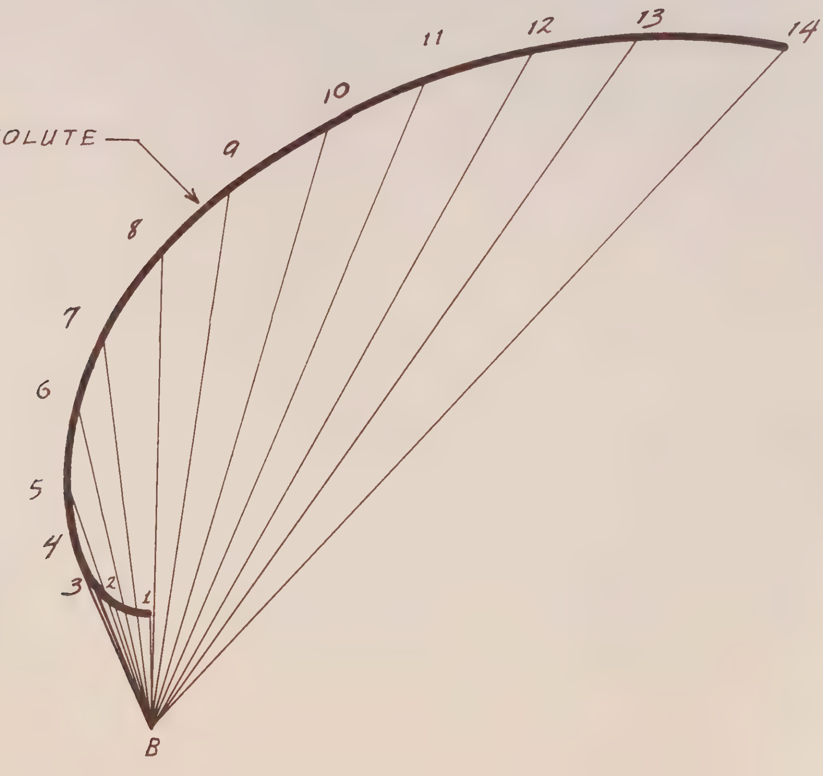
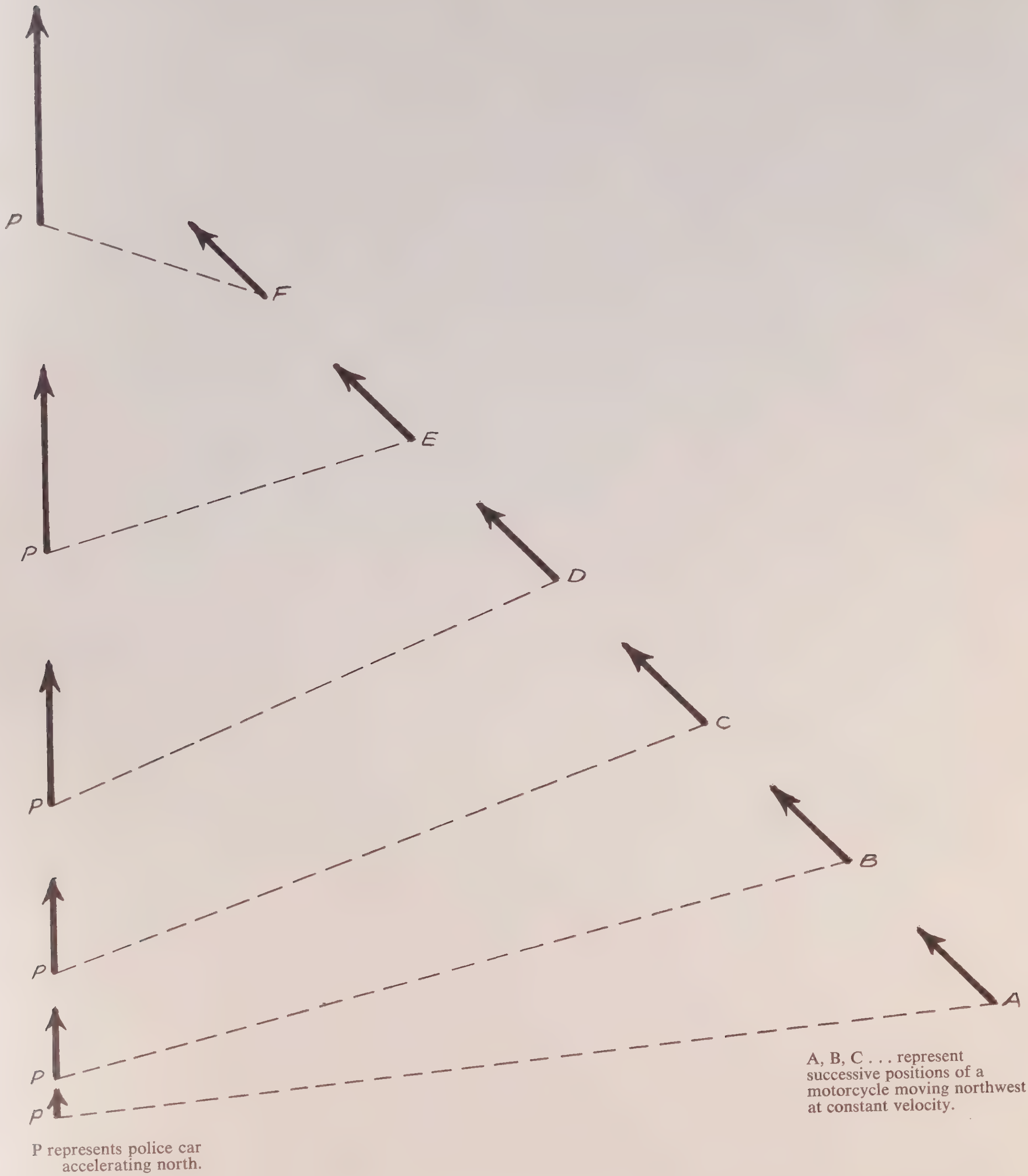


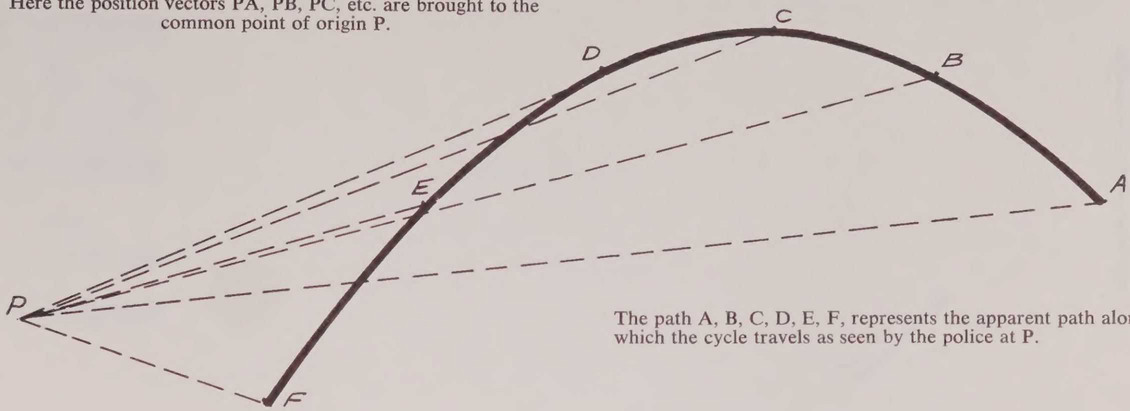
FIGURE 3

3 Another example to establish the idea of a fictitious force in an accelerated frame of reference is illustrated as follows:

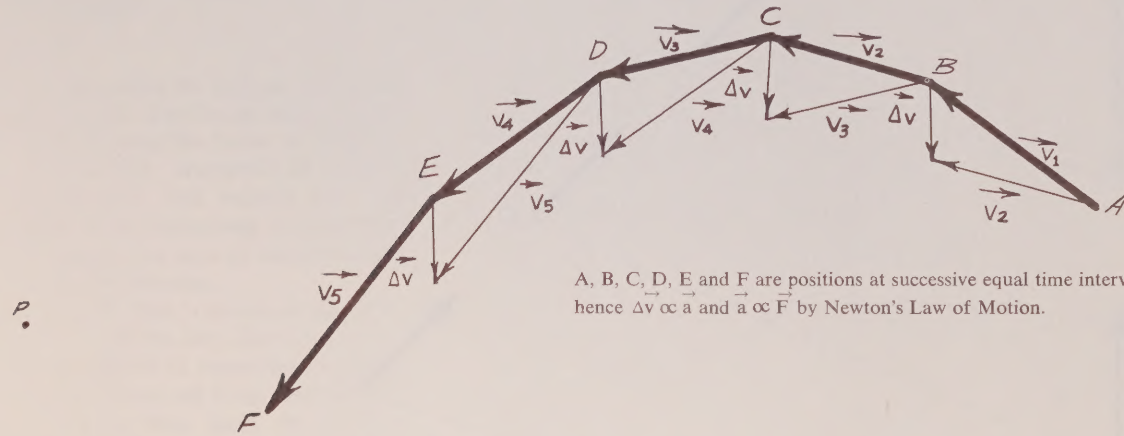


From "earth" frame of reference the motorcycle is travelling with uniform velocity. How does the cycle move relative to the accelerating police car? Relative positions of cycle from police car are shown by broken lines PA, PB, PC etc.

Here the position vectors PA, PB, PC, etc. are brought to the common point of origin P.

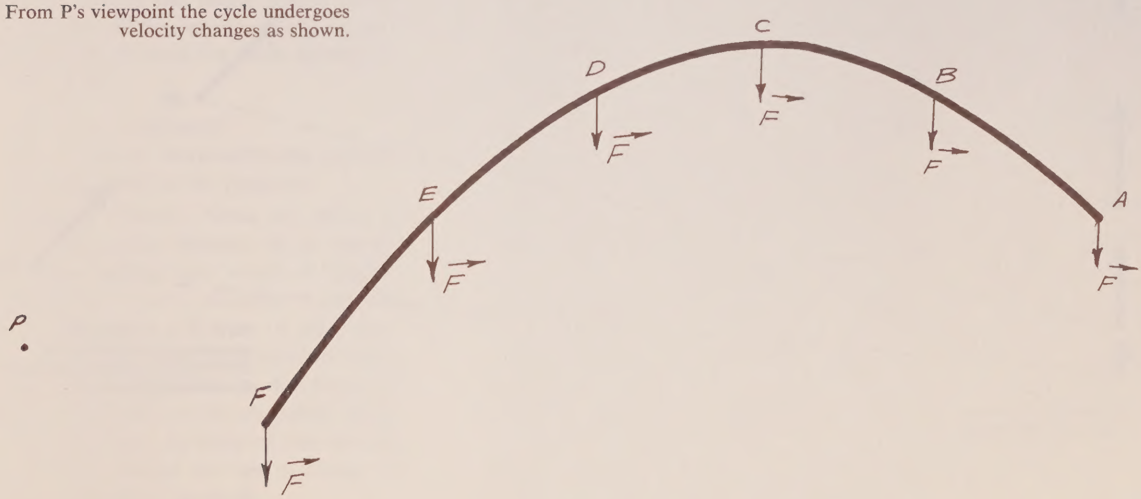


The path A, B, C, D, E, F, represents the apparent path along which the cycle travels as seen by the police at P.



A, B, C, D, E and F are positions at successive equal time intervals, hence $\vec{\Delta v} \propto \vec{a}$ and $\vec{a} \propto \vec{F}$ by Newton's Law of Motion.

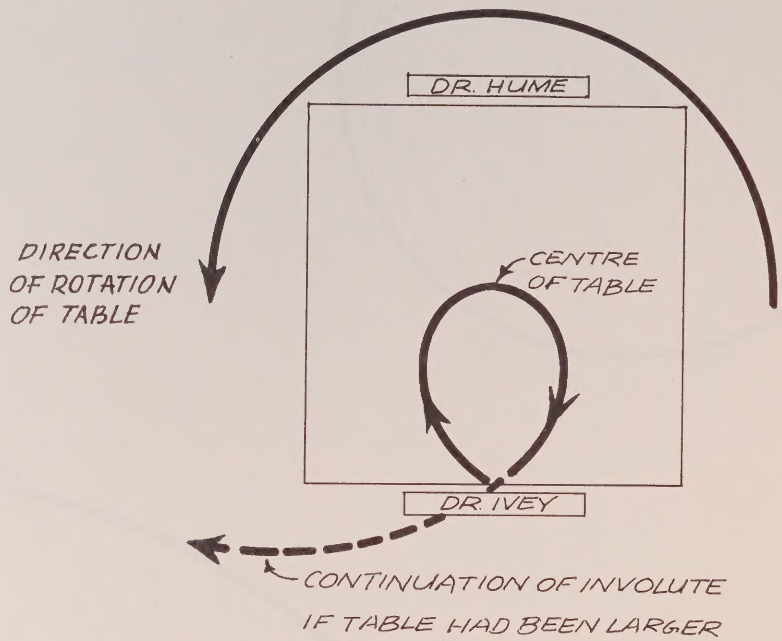
From P's viewpoint the cycle undergoes velocity changes as shown.



From P's viewpoint the cycle is acted upon by a net force $\vec{F}$ causing its apparent acceleration. This force $\vec{F}$ in the frame of reference of the police car must be a *fictitious force*. Note that it is opposite to the acceleration of the police car in the earth frame of reference.

4 It should be established with some emphasis that centrifugal force is the only fictitious force acting in a body in a rotating frame when, and *only when,* the body has no radial motion in this frame when a body does have radial motion, that is, when its distance from the centre of rotation is changing (as illustrated in the film), an *additional* fictitious force called the *coriolis force* must be introduced. The net effect of these two fictitious forces is to cause the object to move in an involute.

When Dr. Ivey, in the film, launched the puck so that it returned to him after half a revolution, the puck was also following an involute. So that this might happen, the puck had to be given the correct speed in the correct direction. The path in the rotating frame of reference would appear as follows:—



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